SOME AIR TEMPERATURE READINGS AT SEVERAL STATIONS ON SLOPING GROUND.

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IT is well known that the mean temperature falls as the elevation increases, and partly on this account certain crops cannot profitably be produced on high land. But it is also recognised that low lying land is subject to lower minimum temperatures, and is therefore more liable to frost[1], than land higher up, and low situations are consequently avoided by fruit and early potato growers. Few actual temperature readings have, however, been published.

We have recently been making an experimental study of the phenomena of spring frosts, and have taken a series of temperature readings at several stations on a slope about a mile and a half long with a total difference in altitude of 580 feet. The slope is on the North Downs, which here run in a S.E. and N.W. direction; away to the S., S.E. and S.W. stretches a large plain. There are eight stations in all, one on the top, two on the banks of the river Stour at the bottom, and the other five come in between; the series form a somewhat irregular line running E. and W. in the positions shown in the following table.

TABLE I.

Position and description of stations.

No. of station	Height above sea level in feet	Height above river at station 7	Distance from station 7	Situation
1	675·21	581·69	7322·5	At the top of the Downs
2	285·34	191·82	5284	Poor pasture field
3	232·34	138·82	4126	Young corn crop
4	174·37	80·85	2691	Uncropped ground; somewhat sheltered from the north by a plantation
5	119·34	25·82	558	Pasture land
6	97·00	3·47	196	"
7	94·52	1·00		River bank, confluence of river and ditch
8	97·00	3·47		River bank, straight part

[1] Theophrastus mentions this fact (lib. v. c. xx.) and also Pliny (lib. XVIII. cc. 69, 70); other old references are given in Boussingault, *Chimia Agricole*, II. 378, and in Warington, *Physical Properties of Soil*, pp. 184 *et seq.*

Stations No. 7 and 8 are intended to find what effect is produced by running water; No. 7 is much more surrounded than No. 8. The river is here 40 ft. wide and very slow. Mr R. St. Biscoe kindly determined the altitudes and distances.

At each station readings were taken at 6 inches and at 2 metres above the ground: they were started on April 14th and had to be discontinued on May 31st. There is a little uncertainty about some of the readings at 2 m., because strong winds shook the thermometers, and at times readings could not be taken but had to be calculated from the results obtained at the stations above and below. The average values used here are probably only slightly affected. Maximum and minimum temperatures were read at stations 1 and 6, but at the other stations minimum readings only were taken; the thermometers were fixed on posts in the open and had no protection whatsoever. All the thermometers used were checked against a standard thermometer with a Kew certificate.

Minimum Readings.

The means of all readings are given in Table II.

TABLE II.

Average minimum temperatures, degrees C., April 14th to May 31st, 1907.

							River bank	
No. of station	1	2	3	4[1]	5	6	7	8
Minimum temperature at 6″ above ground	3·4	3·2	3·3		2·6	2·2	3·3	3·0
" " 2 m. "	3·8	3·4	3·6		3·2	3·2	3·1	3·1

Two distinct phenomena are here involved, the effect of elevation and the effect of water on temperature. Beginning with the former of these it will be noticed that the ground temperature reaches a maximum at the top station, and falls with decreasing altitude to a minimum at No. 6. The temperatures 2 metres up are somewhat higher than the ground temperatures, especially at Nos. 5 and 6. There is the same fall with decreasing altitude, but the gradient is much less marked, and at the four lower stations substantially the same readings are obtained.

[1] Readings spoiled by wind on several nights, and therefore omitted from this Table.

The effect of water will be discussed in detail later on, it is very strikingly shown at No. 7, where the ground temperature is a degree higher than at No. 6, although the two stations are less than 200 ft. apart and lie in the same field. At 2 metres the effect no longer shows.

These phenomena occur to a marked extent on still nights.

TABLE III.

Average minimum temperatures, 11 still nights during experimental period.

							River bank	
No. of station ...	1	2	3	4	5	6	7	8
Minimum temperature 6″ above ground ...	2·8	2·0	2·2	1·9	·6	0	1·5	·9
,, ,, 2 m. ,, ...	3·3	2·5	2·7	2·6	1·3	1·2	1·3	1·4

The difference in ground temperature at stations 1 and 6 has now increased to nearly 3°, and the warming effect of the river is well seen. At 2 metres the temperature is a shade lower at No. 6 than elsewhere, but there is very little difference between stations 5, 6, 7, and 8. These gradients are plotted in Fig. 1; it will be observed that they run parallel as far as station 5.

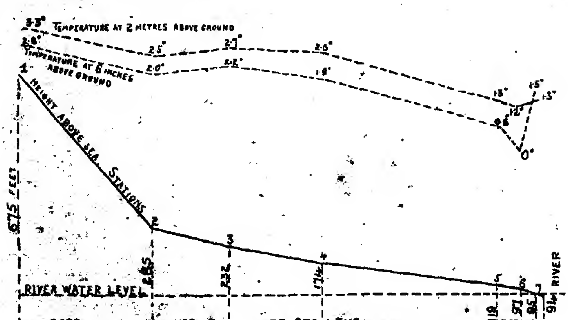

FIG. 1. Temperature gradients on still nights.

The usual explanation of the coldness of the lower ground on still nights is that as the temperature falls the layer of air near the ground is cooled, increases in density and tends to roll down the slope and collect on the plains or in the valleys. Here it displaces the warmer

air, which, being lighter, rises and flows over the upper slopes from whence the cold air has come, keeping these slopes at a higher temperature than the lower ones. This explanation is quite in accordance with all our results.

It is not only on still nights, however, that these effects are produced. We also observed them when there was a south or south-east wind, whilst the reverse effects were seen when the wind came from the north or north-east. We are not prepared to explain this result, but it is probably significant that the south and south-easterly winds blow over the plain and travel up the slope in the same direction as the drift of warm air. Apparently the downward flow of cold air near the ground is not prevented. There might, of course, be a greater cooling of the ground in the valley than on the hill, but this is very unlikely; the moist valley soil probably cools less quickly at night than the dry hill soil. Another important point is that the higher stations are naturally more exposed to the wind, and show the warming of the south wind, and the cooling of the north wind more than the less exposed stations lower down.

TABLE IV.

Average minimum temperatures, nights when wind is blowing.

No. of station	S. or S.E. wind blowing up the slope. Average of 7 nights		N. or N.E. wind blowing down the slope. Average of 6 nights	
	6″ above ground	2 m. above ground	6″ above ground	2 m. above ground
1	6·0	6·2	0·9	0·9
2	5·8	5·5	1·2	1·3
3	5·6	5·8	1·4	1·6
4	5·4	5·8	1·9	2·1
5	4·3	5·6	1·3	1·3
6	3·5	5·0	1·6	1·8
7 (River bank)	5·4	5·1	2·5	2·1
8 (River bank)	4·4	5·0	2·0	1·6

Closely connected with the difference in temperature at stations 1 and 6 is the difference in reading between the thermometers placed at 6″ and at 2 m. On still nights, and with a S. or S.E. wind, the temperature at 6″ is from ·2° to 1·5° lower than at 2 m., while with a N. or N.E. wind the difference is much less, and vanishes at stations 1, 2, and 5.

Effect of the river.

It has already been pointed out that stations 7 and 8 on the river are always warmer than station 6, 196 feet from the edge, but in the same field. Station 7, at the point where a ditch flows in, is almost surrounded by water, and shows a higher temperature than station 8, which is on a straight part. The warming effect is probably due to the high specific heat of water and the absorptive power of its vapour preventing a great fall in temperature during the night; it is only seen near the ground, and disappears at 2 m. The readings at 6 inches are given in Table V.

TABLE V.

Average minimum temperatures at and near river bank.
6″ above ground.

	Station 6, 196 ft. away from river	Station 8, on river bank, straight part	Station 7, on river bank, confluence of river and ditch
Minimum, all nights	2·2	3·0	3·3
Excess on river bank		·8	1·1
Minimum, still nights	0	·9	1·4
Excess on river bank		·9	1·4
Minimum, nights with S. or S.E. wind	3·5	4·4	5·4
Excess on river bank		·9	1·9
Minimum, nights with N. or N.E. wind	1·6	2·0	2·5
Excess on river bank		·4	·9

It should be noticed that the river is only 40 feet wide.

We cannot say how far from the bank the warming effect is perceptible, but practical men have long since recognised that fields and gardens near a river or a large mass of water suffer less from frost than those further away. Instances of this protective action can be found all along the north Kent coast. The Isle of Grain is less liable to frost, and therefore more suited to early potatoes, than the Hundred of Hoo, situated a little further from the water. Fruit close to the coast suffers less from frost than that a little inland. It is noticed in Worcestershire that gardens within 50 yards of the river Avon suffer less than gardens at a greater distance, whilst in California the influence of a river is so well recognised that land along the bank, and particularly at a bend, where the protective effect is intensified, is considered to be more valuable for certain fruits than land elsewhere.

On a slope like the one under consideration three zones can be distinguished, one near the river somewhat protected against frost, a second further away but on the low ground, and liable to frost, a third still further away on the high ground much less liable to frost. These zones are shown diagrammatically in Fig. 2; their relationships are important to the fruit and early potato grower in spring, and to the gardener in autumn.

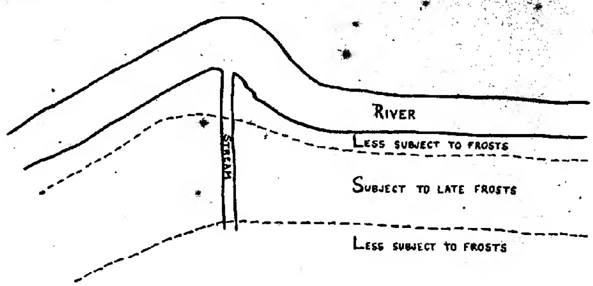

FIG. 2.

Maximum temperatures and temperature amplitudes.

Maximum readings were taken at stations 1 and 6, and the results show that during the day the temperature in the valley is higher than on the hill and in consequence the temperature amplitude is nearly 4° greater.

TABLE VI.

Average maximum and minimum temperatures, April 14th to May 31st.

	Station 1, top of slope	Station 6, bottom of slope	Excess at 6
Maximum	14·3	16·7	2·4
Minimum	3·4	2·2	1·2
Total variation ...	10·9	14·5	3·6

The fact that low land is colder by night and hotter by day than land higher up is well known and is also exemplified in the different character of plant growth in the two situations.

SOME OBSERVATIONS ON "SWOLLEN HEAD" IN TURKEYS.

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The following observations relate to a disease in turkeys, colloquially known as "swollen head," characterised by enormous swellings under the eyes and discharge from the nostrils, which was recently prevalent in some parts of the Eastern Counties. The disease appeared to be confined to turkeys, and was not communicated by them to fowls and ducks with which they mixed. Only turkeys sent to the laboratory were examined, and no opportunity occurred of making an inspection of the birds on the farms on which the disease was prevalent. From the reports of those who had to deal with the birds it was evident that when once introduced the disease spread rapidly. Usually the swellings are so large that the birds are unable to see their food, and unless artificially fed become very thin, but if artificially fed may remain in good health. Sometimes, however, a considerable mortality was produced. In some instances the owners opened the swellings and expressed the gelatinous contents, and washed out the infected cavities with antiseptic solutions. These measures produced some temporary alleviation of the symptoms, and allowed the birds to feed naturally for a day or two. The original condition, however, soon recurred.

Up to the present time very few investigations seem to have been made on the pathology of the lesions or the cause of the disease. Dodd (1905) appears to be the only observer who has described, under the name of "Epizootic pneumo-enteritis of the turkey," a disease in which similar swellings occur. In his cases, however, the swellings were accompanied by marked lesions of the lungs and intestines. In the present instance no lesions of the lungs or intestines, except dilatation of the coeca, in a few cases, were ever found, nor were the bacilli described by this observer ever recovered from the heart's blood or

organs. It is, therefore, possible that two diseases characterised by swellings under the eyes may affect turkeys, or that in more severe epidemics lesions of the internal organs occur which are lacking in the less severe types.

The present investigations consisted of (1) observations on naturally infected turkeys, including bacteriological examinations of the exudates during life and of the affected parts, blood and organs after death; and (2) the inoculation of healthy turkeys with pure cultures of the predominating bacteria found in the naturally infected birds, and with emulsions of the exudates of diseased birds.

As a result of these experiments it has been shown that the disease does not always follow the same course, and that it can be communicated to healthy turkeys in various ways during its different stages. Mainly owing to the limited material and accommodation no specific organism has, however, been isolated, and the cause of the disease has not, therefore, been determined.

It is hoped, however, that these observations in spite of the lack of definite conclusions may be of assistance to those who take up the study of this interesting and economically important disease.

Anatomy. In the turkey's head there is a large cavity, externally covered by skin, which surrounds the lower part of the orbit, and extends forwards almost up to the nostrils. This is a dilatation of the naso-pharyngeal system of air sacs, and communicates with the nasal cavity by a very narrow passage, through which it is filled by air. For the sake of convenience it is here described as the *infra-orbital sac.* Its dimensions and relations are best appreciated by reference to Plate III, fig. 3.

The naturally acquired disease.

Turkey No. 1. (Old Cock.) The bird showed large fluctuating swellings under both eyes. Commencing immediately in front of the eye at the level of the upper lid the swelling extended forwards almost up to the nostril and backwards under the eye to a point about a quarter of an inch behind the palpebral opening. It was most marked in front of the eye preventing the bird from seeing objects nearly in front of it, but also formed a considerable mass under the eye preventing the latter from being completely opened. The swellings were exactly similar in shape and extent on both sides.

A gelatinous fluid slowly exuded from the nostrils which the bird wiped off by passing the beak across the feathers of the back. These

feathers consequently became coated with the exudate and stuck to one another. Some frothy material was occasionally found on the surface of the eye.

The bird found considerable difficulty in feeding, as when the head was lowered the swellings in front of the eyes increased, and the bird was unable to see the dishes containing food, and in fact frequently failed to pick up any, often pecking the floor in the neighbourhood of the dish.

He showed no other evidence of disease and appeared to be in good health.

This bird was kept under observation for nearly two months. During the first two weeks the contents of the swellings were daily expressed through openings which had previously been made. Within a few hours, however, they had again filled up. During the rest of the time it was artificially fed. No difference was noticed in the size or consistency of the swellings and the general health was well maintained. At the end of this time the bird was killed and a careful autopsy made.

Autopsy. All the organs appeared to be normal, including the pericardium and intestines. Cultures on various media from the heart's blood, liver and lungs remained sterile. Sections of the organs showed no pathological lesions.

The swellings were found to be caused by the distension of the infra-orbital sacs by gelatinous, semi-transparent fluid like egg albumen containing some white flocculi. On the left side a small mass of yellowish material, like inspissated pus, was found in the anterior part of the cavity. The nasal cavities also contained some gelatinous fluid, and the mucous membrane appeared somewhat swollen, but was not markedly congested.

No motile organisms or protozoa were found in fresh films. Stained film preparations and cultures were made from the nasal exudate during life and from the gelatinous fluid after death. In both cases the fluid showed small numbers of cells and large numbers of bacteria. The great majority of these belonged to one species, which is described under the name of Bacillus A.

Bacillus A. In film preparations these bacilli were scattered over the field singly or in groups the members of which were arranged at all angles. Two individuals were occasionally found end to end but chains were never observed. The bacilli stained well by Gram's method and by methylene blue. In most cases the ends stained more darkly than the centre, and a light band in the middle was

a conspicuous feature. They all showed rounded ends, and the majority were slightly curved. Considerable variation in size was noted, a few being long, the majority of medium length, and a few short. All showed slight irregularities in width, so that they were never cylindrical, and many showed clubbed ends. They are non-motile and no spores are formed.

In cultures on serum made directly from the gelatinous exudate numerous colonies of this bacillus developed, together with a few colonies of other organisms, probably accidental impurities. In pure cultures it exhibited the following characters.

Serum. After 24 hours incubation at 37° C. small, smooth, circular, moist, dome-shaped, colonies of greyish colour are formed, which show a tendency to coalesce. The bacilli are of medium length, slightly curved, often slightly clubbed, and show a central light band and darkly staining rounded ends. A few long segmented forms are also present. No polar bodies are formed. After 48 hours growth the colonies are larger, and many have coalesced, and long segmented forms of the bacilli are more numerous. *Agar.* After 24 hours growth at 37° C. small, round, flat, grey, almost transparent colonies are formed. The central portion is more opaque than the rest and is surrounded by a very thin grey zone with a granular surface. After 48 hours the colonies increase in size but are similar in shape. Later, however, the colonies lose their rounded form, and throw out spike-like projections. Many long segmented bacilli are found after 48 hours growth. Growth occurs slowly on *gelatin* and the medium is not liquefied. On *potato* after 24 hours growth a slightly yellowish continuous growth is formed, which later becomes decidedly yellow in its thicker portions. Most of the organisms are rounded and appear like diplococci, but a few of the larger forms are to be found. *Broth* cultures grown at 37° C. at first show a very slight surface film, and slight turbidity, and a granular deposit. Later the medium becomes clear. The organisms are long, segmented and clubbed. The reaction of *glucose-broth* is not altered. The bacilli are *non-pathogenic* to guinea-pigs in large doses intra-peritoneally.

Turkey No. 2. (Adult hen.) The right side of the head was normal. On the left side there was a large swelling exactly corresponding in its situation to the swelling in turkey 1. It differed, however, from the latter in being distinctly hard, and in being covered by dry and brown, instead of normal, skin. Fluctuation could only be obtained with difficulty (Plate III, figs. 1, 5). Clear gelatinous fluid exuded from the left nostril, and, as in the case of turkey No. 1, the feathers on the back were coated with this material. The bird was rather thin, but appeared to be in good health and took its food well.

In the course of time the swelling became larger and harder. Five months after the bird was received the swelling was enormous, entirely preventing the bird from using the left eye. The palpebral fissure, however, remained widely open owing to the lower palpebral conjunctiva being forced through it by the accumulation of material under it (Plate III, fig. 2). Shortly afterwards this portion of the con-

junctiva ulcerated, and a considerable amount of yellowish, foul-smelling material was discharged in large masses, and so diminished the swelling that the cornea again became visible. Up to this time the eye itself was apparently uninjured, the bird fed well and the general health seemed unaffected.

Within the next month the swelling again increased in size, and the bird refused to eat, and becoming very thin and weak was killed.

Autopsy. The body was extremely emaciated, but no macroscopic or microscopic lesions were found in any of the cavities or organs. Cultures from the heart's blood and several of the organs remained sterile. On the right side the eye and infra-orbital cavity were normal.

On the left side the whole of the infra-orbital cavity was filled with a dense, laminated, yellow cheesy mass of foul-smelling material, which also covered the anterior surface of the eye. At one place the cornea had become ulcerated, and similar material filled the anterior chamber. This lesion was evidently very recent. The left nasal cavity was filled with clear gelatinous fluid containing small flakes, but the walls showed no inflammatory changes. The mouth was normal.

Sections made from fragments of the material discharged during life showed that it was mainly composed of cells in various stages of degeneration. In the central portions a few pale staining nuclei only were seen imbedded in granular débris, but nearer the edges the nuclei and cells were more distinct. The latter are round and possess large round nuclei, and closely resemble the cells seen in the gelatinous exudate of turkey No. 1. No fibrin was found. In the central portions groups of bacteria were occasionally seen, but near the surface the bacteria were present in enormous numbers, lying singly or in large masses. In sections stained by Weigert's method many of the bacteria were well stained. Sections, obtained at the autopsy, prepared from masses of material filling the cavity were similar in all respects, except that the Weigert staining bacilli were much less abundant.

Bacteria. Fresh and dried film preparations and cultures were made at various times from the discharge during life and from the contents of the cavity after death. Films of the *gelatinous exudate* from the nostril during life showed numerous cells, the majority with large round or oval nuclei, mixed with other cells of various kinds. In these films bacteria were very numerous. The Bacillus A previously described and another later described as Bacillus C were occasionally seen, but the species B was much more common. A few large thick bacilli were also seen and many small cocci. Cultures showed Bacillus B to be the predominating organism. Film preparations from the *yellow material* discharged during life showed the same cells as the fluid but in much greater numbers. The great majority were undergoing degenerative changes. Bacteria were present in great numbers including cocci and the bacilli mentioned. Cultures on serum gave very large numbers of Bacillus B, which possesses the following characters.

Bacillus B. On *serum* after 48 hours growth at 37° C. small, round, slightly yellow, granular colonies appear situated in small depressions in the medium. Liquefaction does not occur on further growth. The organisms are non-motile, do not form spores, and have no definite arrangement in the field. They have rounded or slightly pointed ends. Some are of medium length and slightly curved, and others are long and markedly curved. Considerable enlargement of one or both extremities is very common except amongst the shortest forms, and some of the larger forms show enormous clubbed ends.

They stain well by methylene blue and also by Gram's method. By the former method all show differential staining of the protoplasm. The shorter forms show a central oval darkly staining area and pale extremities, while the long forms frequently show two or three of these dark areas. On *agar* after 24 hours growth at 37° C. round, raised, smooth, moist white colonies without distinctive features are formed. Most of the bacilli have marked swellings at one or both ends, almost all are more or less curved and have nodosities at various points, and some are distinctly segmented. These features are much exaggerated on further growth. No polar bodies can be demonstrated. On *potato* the growth is at first invisible, but becomes apparent after six days' incubation. Large distorted involution forms are rapidly developed. In *broth* no surface film is produced, but a good growth occurs in the form of a granular sediment while the medium remains clear. Neither acid nor gas is produced in media containing *glucose*, *saccharose*, *maltose*, *lactose*, *laevulose*, or *glycerine*. On *gelatin* growth occurs slowly and the medium is not liquefied. No change is produced in *milk*. The organism is *non-pathogenic* to guinea-pigs in doses of 2 c.c. intra-peritoneally and subcutaneously.

Films and cultures from the material obtained at the autopsy showed large numbers of bacteria. These differed in species, however, from those previously obtained, since very few bacilli belonging to types A or B were seen or cultivated. *B. pyocyaneus* was isolated and appeared to be typical in all respects including pathogenicity to guinea-pigs. The majority of bacilli belonged to the species C about to be described.

Bacillus C (Plate III, fig. 7). In film preparations from the original cheesy material the organisms appear as medium length, rather wide rods, with rounded ends. They vary greatly in length, and stain poorly but evenly with the ordinary dyes, and do not retain Gram's stain. On *agar* after 24 hours growth at 37° C. white, flat, smooth, round colonies are formed of somewhat slimy consistency. In smear preparations made from these colonies the bacilli tend to stick together in masses. The bacilli are medium length, rather wide rods with rounded ends which stain evenly. Occasionally long forms occur, and sometimes short almost round forms. They are non-motile and no spores are formed. This bacillus grows well on *serum* forming medium sized, whitish, round, soft colonies, which rest in small depressions in the medium. Liquefaction does not occur. The bacilli resemble those from agar cultures. Good growth occurs on *gelatin* and the medium is not liquefied. The colonies are small, irregularly rounded, granular and semi-transparent. The organisms are short and uniformly staining. *Broth* at first shows marked turbidity but the growth soon settles in the form of a thick, whitish, flocculent deposit. On *potato* a copious white slimy growth is produced in 24 hours. Subsequently the growth becomes very abundant, but is never coloured. Media

containing *glucose*, *lactose*, *maltose*, *mannite*, and *dextrin* all become markedly acid. *Milk* is made acid and firmly clotted within 48 hours. Guinea-pigs die within 18 hours after intra-peritoneal inoculation of 1 c.c. of broth culture. At the autopsy a purulent peritonitis is found with large numbers of organisms in the fluid.

Turkey No. 3. (Young hen.) Both sides were affected with soft fluctuating swellings exactly similar in position and size to those of turkey No. 1. There was also a considerable amount of glairy discharge from both nostrils, and the feathers of the back were plastered together with this material. The bird was very thin, and owing to an ulcerated condition of the upper mandible kept its mouth slightly open.

Cultures made from the nasal discharge showed *B. pyocyaneus* and Bacilli B and C. During the first three weeks' observation the swellings became gradually smaller, and after four weeks that on the left side had completely disappeared and the other was scarcely visible. The discharge from the nostrils, however, continued and the bird looked very thin and ill. A few days later the swellings again became visible, but soon again disappeared. At the end of 8 weeks' observation the bird appeared very thin and had great difficulty in feeding owing to the condition of its beak. It was then killed.

Autopsy. Except in the case of the coeca no lesions were found in any of the organs or cavities of the body either macroscopically or microscopically, and cultures from them remained sterile. The distal extremities of both coeca were greatly distended by frothy gelatinous-looking material with a foetid odour. Small masses of yellow coagulum were sticking to the walls. Amongst other organisms Bacillus C was isolated from them.

Both infra-orbital cavities contained fluid similar to that obtained from turkey No. 1. Cultures showed a few colonies of *B. pyocyaneus* and Bacillus B, and a considerable number of Bacillus C. Cocci and other organisms were also present.

Turkey No. 4. (Young hen.) This bird showed no signs of the typical swellings, but suffered from difficulty in breathing, and the nostrils were stopped up by hardened secretion and the eyes frequently filled with frothy fluid. It was then very thin and weak, and was considered to be in the last stages of the disease. After a few days' observation it was killed and an autopsy made.

Autopsy. The trachea contained three worms (*S. trachealis*), and the tracheal mucus was full of their ova. All the other organs appeared to be normal and cultures from them remained sterile. The infra-orbital cavities contained practically no fluid, and only a few cocci

appeared in cultures. From the tracheal mucus, however, an organism apparently identical with Bacillus A was cultivated.

Experiments on turkeys.

Turkey A. (Young cock.) Attempts were made to infect this bird by several methods: (1) 1 c.c. of gelatinous material from turkey No. 2 was injected into the right infra-orbital cavity, and some of the same material was introduced by means of a swab into the left nasal cavity and into the mouth. The bird was carefully watched for four weeks but developed no symptoms of the disease. (2) At the end of a month a broth culture made directly from gelatinous material and incubated for 48 hours was mixed with the food. During the next four weeks the bird remained in perfect health. (3) Ten lice from a naturally infected turkey were now placed on him, and again the bird showed no symptoms for a month. (4) During the next week his food was contaminated with the excrement of a diseased turkey. The bird showed no symptoms during a month's observation. (5) The bird was now placed for six weeks in the same cage with an infected turkey without showing any signs of the disease. (6) Finally 2 c.c. of cheesy material from the eye of turkey No. 2, emulsified in salt solution, was inoculated into the right infra-orbital cavity. The next day a slight swelling appeared, which increased considerably during the next two days. In five days the swelling was of the same size and consistency as the swellings observed in turkey No. 1, and caused partial closure of the eye. A considerable quantity of gelatinous fluid escaped from the right nostril, and this could be increased by pressure over the swelling. Smears and cultures from this material showed numerous organisms including Bacilli B and C. During the next month the swelling became distinctly harder, and the discharge from the nostril more abundant, so that it constantly dripped from the beak, and plastered down the feathers of the back where the beak was wiped. Within the next three days, however, the discharge completely ceased, and the nostril was occluded by coagulated material. A week later the bird was killed and examined after being under observation for 23 weeks.

Autopsy. All the organs and cavities appeared normal, and microscopic sections showed no lesions. Cultures from the heart's blood, lung, and liver remained sterile. The left side of the head was normal, and no changes were noticed in the mouth or left nasal cavity.

The inoculated infra-orbital cavity contained a yellow mass forming a perfect cast (Plate III, fig. 6) of the cavity and its ramifications. The membrane lining the cavity was rough and injected, but in no place intimately adherent to the cheesy material. The eye was unaffected. The mucous membrane of the right nasal cavity looked swollen, and small masses of yellow material were found in the crevices.

Smears from the yellow mass showed many cells, mostly undergoing degeneration, and numerous bacteria, including Bacilli B and C, and a few streptococci and other organisms. Cultures showed a few colonies of Bacillus B and numerous colonies of Bacillus C.

Sections of the nasal mucous membrane showed some dilatation of the vessels and many inflammatory cells. Sections of the lining membrane of the infra-orbital cavity showed that, except in some of the recesses, the epithelium had disappeared and was replaced by granulation tissue. The subcutaneous tissue between the skin and the infra-orbital cavity contained much new formed fibrous tissue, and was infiltrated with inflammatory cells. The bacteria had not, however, penetrated deeply.

Turkey B. (Hen.) Crushed cheesy material from turkey A was inoculated into the right infra-orbital cavity. In three days a slight swelling appeared which gradually increased in size. After 18 days the swelling was still of moderate size and soft, and a gelatinous discharge had developed from the nostril. In the next week the latter increased in amount and cultures showed that it contained some cocci, a few colonies of *B. pyocyaneus* and Bacillus C, and a bacillus described as D in very large numbers. During the next 15 days the swelling gradually became harder, and the bird took its food badly and became weak. On the 51st day of the experiment the bird was found dead.

Autopsy. There seemed to be slight dilatation of the intestinal vessels, but all the other organs appeared healthy. Microscopic sections showed no lesions, and cultures from the heart's blood, pericardium, and liver remained sterile. Cultures from the lungs showed a few colonies of the Bacillus A type. The left side of the head was normal (Plate III, fig. 3). The right infra-orbital cavity contained foul-smelling cheesy material similar to that found in other cases (Plate III, fig. 4). The eye was not affected. Cultures from the affected cavity showed numerous colonies of Bacillus C and smaller numbers of Bacillus D and *B. pyocyaneus.* Cultures from the mouth showed the same organisms as well as various other bacilli and cocci.

Bacillus D. In smear preparations of the gelatinous material these bacilli were found in groups usually composed of 3—10 individuals, but occasionally containing as many as 40—50. Most of the specimens were curved, showed well marked segmentation, and well defined polar bodies (Plate III, fig. 8).

On *serum* after 24 hours growth at 37° C. the colonies are small, round, yellowish, and dry looking. After three days' incubation the colonies become very large. The centre is much raised and deep yellow in colour and is surrounded by a flat pale yellow zone. The whole colony has a very granular appearance. If the colonies are crowded together they coalesce to some extent to form a film which appears to have a wrinkled surface owing to the irregularities in height of the component colonies. The bacilli bear a remarkable resemblance to true diphtheria bacilli. They are of medium length, with rounded ends, and are usually slightly curved. Clubbed extremities are common and many have irregularities in their length. Some branching forms were seen. They retain Gram's stain, show polar bodies, terminal and central, with Neisser's stain, and differential staining of the protoplasm with methylene blue. In some dark and light bands alternate causing a segmented appearance, whilst in others these areas are irregularly placed. They are non-motile, do not form spores, and have no characteristic arrangement. On *agar* large, white, granular, irregular, dry-looking, heaped up colonies are formed, which after a few weeks' growth increase in size and become wrinkled. The bacilli are shorter than when grown on serum and many coccus-like forms can be found after 48 hours growth. On *potato* large, yellow, dry-looking, discrete colonies are produced. At first the bacilli are like those from serum cultures, but later large irregular involution forms are common. Good growth occurs on *gelatin* and large, dull-yellow, granular colonies are formed. The medium is not liquefied. In *broth* a whitish wrinkled film is produced on the surface, and a yellowish flocculent deposit. Acid is produced in media containing *glucose*, *galactose*, and *laevulose*, but not in media containing *lactose* and *glycerine*. This organism is *non-pathogenic* to guinea-pigs.

Turkey C. (Young bird.) The right infra-orbital cavity was inoculated with ·5 c.c. of gelatinous exudate from the nostril of turkey B. No symptoms appeared during three weeks' observation. Later this bird was inoculated with 1 c.c. of a 48 hours broth culture of Bacillus A, derived from the lung of turkey B, without effect. Some weeks later the bird was placed in the same cage as a naturally infected bird. After eight days a slight swelling appeared on the right side, and within the next 14 days considerable swellings had developed on both sides. During the next month the swellings gradually decreased and finally almost disappeared. The bird was then killed.

Autopsy. All the organs appeared to be healthy, and cultures from them remained sterile. The infra-orbital cavities only contained very small quantities of a milky fluid from which Bacillus C and *B. pyocyaneus* were cultivated. Although the coeca showed no lesions, Bacillus C was cultivated from them.

Turkey D. (Young bird.) The right infra-orbital cavity was inoculated with ·5 c.c. of a broth culture of a recently separated culture of Bacillus C. No symptoms were observed. Several weeks later the bird was placed in the same cage as a naturally infected bird. Within a week it developed considerable swellings on both sides, which gradually increased for about a month, but almost disappeared within the next month. In the ninth week of observation the bird suddenly died.

Autopsy. The bird was rather thin, but the only lesion found was distention of the coeca. Both infra-orbital cavities contained small quantities of cheesy material from which Bacillus C was cultivated. The same organism was isolated from the contents of the coeca.

Turkey E. (Young bird.) Gelatinous nasal exudate was placed in both nasal cavities and in the mouth on three consecutive days without effect. Some weeks later the right infra-orbital cavity was inoculated with a recent culture of Bacillus D without producing any symptoms. Several weeks later some gelatinous nasal exudate was placed in the right nostril. In eight days there was a discharge from the nostril, which continued for 15 days, when a slight swelling developed. Soon after the other side became swollen, and 40 days after the beginning of the experiment both sides were considerably swollen. The bird was then killed.

Autopsy. All the organs appeared to be healthy and cultures from them remained sterile. The right infra-orbital cavity contained very little gelatinous fluid, and the left similar fluid and some cheesy material. Cultures were overgrown by a film-forming organism.

Turkey F. (Young bird.) ·5 c.c. of a recently isolated culture of *B. pyocyaneus* was inoculated into the right infra-orbital cavity without producing any effect. Some weeks later 1 c.c. of an emulsion of the cheesy material from turkey B was inoculated into the left infra-orbital cavity. A very slight swelling developed which gradually disappeared.

Turkey G. (Young bird.) This bird lived for a considerable time in the same cage with turkey B without developing any symptoms. Some weeks later some gelatinous nasal discharge was given to the bird on pieces of lettuce. A week later a discharge from the nostril appeared, which continued for about five weeks, when both sides became slightly swollen. Shortly afterwards the discharge ceased, and the swellings gradually disappeared.

Turkey H. (Young bird.) This bird was inoculated with ·5 c.c. of

gelatinous material into the left infra-orbital cavity. After five days a distinct swelling was evident, and a few days later discharge appeared at the nostril. Soon afterwards the other nostril began to discharge, and this was followed by a swelling. Within a month there were large, soft, fluctuating swellings on both sides. A fortnight later the bird died.

Autopsy. With the exception of the coeca all the organs and cavities of the body appeared to be healthy and cultures from them remained sterile. Both the coeca showed some dilatation at their distal ends. Considerable quantities of gelatinous fluid were found in both infra-orbital cavities. Cultures from the coeca showed numerous bacteria of various kinds, and amongst others Bacillus C was isolated. Cultures from the gelatinous fluid of the infra-orbital cavities showed very few bacteria and none belonging to the species described.

Experiments on other birds.

Intra-muscular injection of some gelatinous fluid into a pigeon produced no effect, and several experiments including inoculations of pure cultures of Bacilli B, C, D, and *pyocyaneus* and gelatinous and cheesy material into chickens were all negative.

Summary.

In experimentally infected birds a clear viscid discharge from the nostril is sometimes the first symptom noticed, and may occasionally be the only one for a long time (turkey E). This is followed by a soft fluctuating swelling under one or both eyes. After the development of a well-marked swelling, the course of the disease may vary both in naturally and experimentally infected birds. In some cases the swelling gradually diminishes and finally disappears (turkeys 3, C, D, F, and G), in other cases the soft fluctuating swelling persists for considerable periods (turkeys 1, E and H), and in others the swellings become hard and the gelatinous contents are replaced by cheesy, foul-smelling material (turkeys 2, A and B). The latter condition may be due to secondary infection. Sometimes the disease only attacks one side leaving the other quite normal. Death occurred in some instances, but could not be definitely attributed to the disease.

Careful autopsies made on all the turkeys which died or were killed failed to show any gross or microscopic lesions of the cavities or principal organs of the body. Cultures taken from the heart's blood, organs and

cavities all remained sterile, except in the case of a single culture from the lung of turkey B, which showed a few colonies of Bacillus A. In three instances apparently abnormal dilatation of the coeca was found, but even in these cases no indications of inflammatory reaction were noticed. In six birds no lesions of the coeca were noticed. In all cases, therefore, the disease was confined to the infra-orbital and nasal cavities.

The local conditions varied according to the character of the exudate filling the infra-orbital cavity.

In some cases, which were apparently recovering, only a small quantity of gelatinous material resembling egg albumen together with a few white flakes was found. In other cases in which the swelling was considerable large quantities of this material were present. Even in these cases very few signs of inflammatory reaction were noticed in sections of the walls of the cavities. In the cases in which whitish foul-smelling material was present the conditions were very different. The whitish-yellow firm mass completely filled the whole cavity, extending into the various recesses. In some instances it adhered firmly to the walls, but in one case could with some difficulty be removed as a perfect cast. Sections of the walls showed destruction of the lining membrane and extensive inflammatory changes. The nasal cavity on the affected side usually contained semi-gelatinous fluid resembling that found in the infra-orbital cavities in the milder cases, but in no instance was blocked by cheesy material. The mucous membrane often had a swollen gelatinous appearance, but never showed signs of acute inflammation. No lesions were ever found in the mouth.

Attempts were made to reproduce the disease by various methods, but of those tried more than once only one was uniformly successful. The disease was three times reproduced by means of the characteristic gelatinous material, once by its application to the nostrils, once by direct inoculation into the infra-orbital cavity, and once by feeding. On the other hand application to the nostrils failed once and direct inoculation twice. Inoculations with cheesy material were made three times and were successful on each occasion. Confinement in the same cage with a diseased bird was twice successful, and twice unsuccessful.

Contamination of the food with the excreta of a diseased turkey, and transference of lice from a diseased to a healthy bird were each tried, once unsuccessfully.

Inoculations into the infra-orbital cavities of healthy turkeys of

recent pure cultures of the organisms (Bacilli A, C, D, and *pyocyaneus*), present in large numbers in the exudate of diseased turkeys, all failed.

The experiments are neither sufficiently numerous nor conclusive to warrant any decided opinions on the cause of infection or the period of greatest infectivity. They seem to indicate, however, that the disease may be naturally contracted by contact with diseased birds during the gelatinous stage, by contamination of the nostrils with gelatinous material and by contaminated food. Experimentally the direct inoculation of cheesy material is the most certain method.

In spite of the negative results of the inoculations of pure cultures the relations of the predominating bacteria to the various stages are of considerable interest.

On several occasions fresh preparations of the various types of exudate were examined, but no motile bacteria or protozoa were noticed, and specimens stained by Giemsa's method did not show any organisms resembling protozoa.

In each instance one or at most two types of bacilli were present in such enormous numbers that without further investigation they might well have been regarded as the cause of the disease. Cultures were made from the fluid exuding from the nostrils of five diseased birds. Bacillus C was found four times, Bacillus B three times, Bacillus A and *B. pyocyaneus* twice each and Bacillus D once. Cultures from the gelatinous contents of the infra-orbital cavity of turkey 1 showed Bacillus A almost in pure culture, and from turkey 3 Bacilli B, C and *pyocyaneus* were obtained. Five sets of cultures were made from the cheesy material of various birds. All showed Bacillus C. Two showed Bacillus B also, one Bacillus D and three *B. pyocyaneus*.

In these 13 sets (7 turkeys) of cultures, Bacillus C was found 10 times (6 turkeys), *B. pyocyaneus* 6 times (4 turkeys), Bacillus B 6 times (3 turkeys), Bacillus A 4 times (2 turkeys), and Bacillus D twice (1 turkey). Moreover Bacillus C was isolated from the distended coeca of three turkeys, and the normal coeca of one turkey.

It is, therefore, seen that Bacillus C was almost constantly and *B. pyocyaneus* very frequently present. The other organisms were each present on at least one occasion in very large numbers.

The bacilli called A and B and more especially D seem to belong to the diphtheroid group. Organisms belonging to this group have been found by several observers in the mouths of healthy and diseased birds (Macfadyean and Hewlett (1900) in pigeons, Harrison (1901),

Guerin (1901), Graham-Smith (1904), and others in fowls). Similar organisms (*B. xerosis*) are found in the normal human conjunctiva and in those of some animals. In the human subject diphtheroid bacilli have been encountered in the throat, nose, ear, genital organs, and on the skin under various conditions. Considering the wide distribution of this group the occasional presence of members belonging to it in a lesion closely connected with the nose and eye is, therefore, not very surprising. They are, however, of considerable interest from two points of view. Firstly they occurred in some cases in such numbers, doubtless due to favourable conditions for multiplication, that without control observations and experiments they might well have been regarded as the cause of the disease, and secondly, in view of the diagnosis of true diphtheria in fowls and turkeys by some authors without sufficient bacteriological evidence, the extraordinary morphological resemblance of Bacillus D, and some examples of Bacilli A and B, to the true diphtheria bacillus demonstrates the necessity for careful cultural and animal experiments before a diagnosis of diphtheria in birds can be made.

B. pyocyaneus though capable of giving rise to various lesions seems often to be a harmless saprophyte. In these cases though pathogenic to guinea-pigs it did not appear to have any relation to the disease.

The case of Bacillus C is, however, different. It was almost always present in greater or lesser numbers, and was extremely pathogenic to guinea-pigs. On the other hand, in the one experiment in which a pure culture was injected, no effect was produced in a turkey. In estimating the value of this negative experiment the fact must be borne in mind that on two occasions gelatinous exudate applied to the nostrils, and on two occasions the inoculation of this material into the infra-orbital cavity, produced no symptoms, though subsequent experiments proved that under both conditions the disease could be reproduced in turkeys.

It is possible that the disease may be due to other bacteria or cocci, which were never present in very great numbers, or to ultra-microscopic organisms such as are known to give rise to some diseases.

The disease resembles that described by Dodd (1905), in being characterised by the presence of large fluctuating swellings under the eyes, but differs in the fact that the lesions are almost entirely local. Dodd observed thick creamy deposits in the mouth, consolidation and yellow foci in the lungs, and marked lesions of the intestines. One of

[illegible], a medical man, from whom he received some of his specimens, also observed very extensive lesions in the lungs. Dodd further found organisms of the fowl-cholera type in the gelatinous material, heart's blood and organs. Neither bacilli of this type nor the lesions just mentioned were ever encountered. Dodd's bacilli were pathogenic for pigeons, producing dry necrosis at the seat of inoculation, diphtheritic deposits in the mouth, congestion of the lungs and intestines and septicaemia. They were non-pathogenic for fowls, but produced local lesions in guinea-pigs and death in rabbits. He assumes that these organisms were the cause of the disease but made no experiments on turkeys.

In conclusion I wish to express my very sincere thanks to Mr T. B. Wood of the Agricultural Department for calling my attention to the disease and for supplying me with all the turkeys both healthy and diseased.

Conclusions.

(1) The characteristic fluctuating swelling is due to the accumulation of gelatinous material in the infra-orbital cavity.

(2) The swelling may disappear and the bird recover, or the swelling may, in spite of frequent washing out of the cavity, remain for months in the same condition, or the gelatinous material may be converted into cheesy, foul-smelling material. Death occasionally takes place whatever course the disease follows.

(3) With the exception of occasional distention of the caeca, which may have no connexion with this disease, the lesions are confined to the head.

(4) Bacilli of the diphtheroid group (A, B and D) are frequently found in the exudate, and a pathogenic organism (Bacillus C) is almost invariably present, often in very large numbers. Up to the present, however, the latter has not been definitely proved to be the cause of the disease. All attempts to reproduce the disease by means of pure cultures of these organisms failed.

(5) The disease can be reproduced most certainly by the inoculation of cheesy material into the infra-orbital cavity, but can also be reproduced by inoculating the infra-orbital cavities, or smearing the nostrils, or contaminating the food with the gelatinous exudate, or by close contact with the diseased birds.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

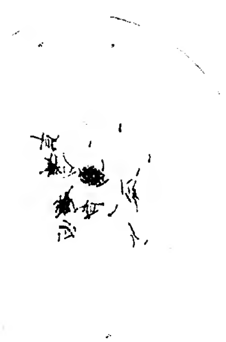

Fig. 8.

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GRAHAM-SMITH, G. S. (1904). *Journ. of Hygiene*, IV. p. 258.
GUERIN, C. (1901). *Ann. de l'Inst. Pasteur*, XV. p. 941.
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MACFADYEAN, A. and HEWLETT, R. T. (1900). *Trans. Path. Soc.* LI. p. 13.

EXPLANATION OF PLATE III.

Fig. 1. Photograph of the left side of the head of Turkey No. 2 at an early stage of the disease when the swelling was soft. The swelling is mainly in front of the eye which is partially closed.

Fig. 2. Photograph of the left side of the head of the same turkey at a later stage. The swelling had by this time increased greatly in size and had become hard. The accumulation of cheesy material under the lower conjunctiva had forced it over the cornea to such an extent that the palpebral fissure was kept widely open. At this period the eye had not become involved.

Fig. 3. Photograph of a dissection of the left side of the head of turkey B to show the extent of the normal infra-orbital cavity.

Fig. 4. Photograph of a dissection of the right side of the head of turkey B to show the infra-orbital cavity filled with white cheesy material.

Fig. 5. Photograph of the upper surface of the head of turkey No. 2 to show the extent of the swelling on the left side. In order to secure a white background the bird's head was thrust through a piece of white filter paper. (Same stage as fig. 1.)

Fig. 6. Photograph of the cheesy contents of the right infra-orbital cavity of turkey A removed in the form of a cast. (Rather larger than the natural size.)

Fig. 7. Drawing of a smear preparation of cheesy material stained with methylene blue. Most of the bacteria seen belong to the species C. (Zeiss $\frac{1}{12}$ Oil. Imm. Oc. 4.)

Fig. 8. Drawing of part of a section stained by Weigert's method of some of the cheesy material from the right infra-orbital cavity of turkey B. Groups of Bacillus D are shown amongst the nuclei of the cells. Bacteria which do not stain by this method cannot be seen. (Zeiss $\frac{1}{12}$ Oil. Imm. Oc. 4.)

THE FLOCCULATION OF TURBID LIQUIDS BY SALTS.

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It has long been recognised that a trace of soluble salt will bring about the flocculation of the material suspended in a turbid liquid; and because of its bearing upon such practical matters as the clearing of drinking water, the deposition of silt at the mouths of estuaries, and the improvement of the texture of heavy soils, the process has received a considerable amount of investigation. It is probably related to the flocculation of colloids by similar reagents; the fine particles of clay which chiefly cause the turbidity of natural waters being composed of a hydrated silicate of alumina and other bases possessing properties akin to those of the colloids. Indeed Schloesing has proposed to call that portion of clay material which remains obstinately suspended in water, sometimes for days together, 'colloid clay,' as something distinct in kind from the other particles in the soil. However it is reasonable to suppose that the distinction between the 'colloid' clay and the rest is in the main one of size, the colloid particles being so small as to be beyond the limits of microscopic vision, just as the true colloids may be regarded as consisting of very large molecules, lying between the molecules which go into solution and the molecular aggregates that remain in water as suspended solids.

Various theories have been proposed to account for the phenomenon of flocculation (see Schulze, *Journ. Prac. Chem.* 25 (1882), 431; Picton and Linder, *Trans. Chem. Soc.* 67, 1895, p. 63; Whetham, "Theory of Solutions," *Phil. Mag.* v. 48, 474 (1899); Joly, *Compt. Rend. du VIII^e^ Congrès Géologique International*, 1900; Spring, *Rec. Trav. Chim. Pays Bas*, 1900, p. 222, which paper also contains a bibliography), but since they did not seem to accord with other observations on the behaviour

of saline solutions towards clay, the authors decided to re-examine the whole subject.

Since the flocculation of 'natant' material and the clearing of the turbid liquid is a question of degree, depending on such factors as the strength of the flocculating salt solution, time, temperature, &c., no absolute measure of flocculation can be obtained. Only a comparative method of experiment can be adopted, and much of the difficulty of correlating the work already done lies in the want of definition of what the author has meant by flocculation. For the present investigations a standard material was first prepared: this consisted of a purified kaolin from which the coarser particles had been separated by decantation in water; it would remain suspended in a column of water 7·5 cm. high for more than 24 hours and was made up of particles less than 0·002 mm. in diameter.

A stock of this having been prepared and suspended in a large bulk of water, 10 c.c. were withdrawn for each experiment after brisk shaking, a quantity that was found to contain 0·2219 gram. of kaolin.

The experiments were carried out in glass cylinders holding 200 c.c. of water to which the 10 c.c. of kaolin suspension were added together with a measured quantity of a standardised solution of the flocculating salt, the whole being then thoroughly stirred. The cylinders stood in an unheated room free from vibration or much change of temperature, and after a few hours, when clearing had sufficiently progressed, each jar was matched by eye with one or other member of a standard series. This standard series was made up each time of a number of cylinders in which the flocculation was effected by regular increments of calcium nitrate, so as to obtain concentrations lying between $n/40{,}000$ and $n/2500$. Thus by preliminary trials and by varying the concentration of the substance under examination it could be matched against one of the standard jars and could be brought into a comparative numerical scale indicating its flocculating power, on the assumption that this flocculating power is inversely proportional to the amount of substance required to produce the standard effect. Thus if a concentration $=n/2000$ normal of a substance A is required to produce the same result as a concentration of $n/10{,}000$ calcium nitrate, it is assumed that the flocculating power of A is only one-fifth that of calcium nitrate. The photographs, Plate IV, Fig. 1, show the character of the results obtained in three series of these experiments. It was found to be important to work with equal quantities of standard material of fairly uniform fineness of grain; the relations are obscured if the amount of

material varies too widely, or if it contains many coarse particles, because of their tendency to drag finer ones down with them on settlement.

Only certain substances seem to be capable of indefinite suspension in water, of assuming what the authors call the 'natant' condition, however finely divided they may be. For example among the class of bodies likely to be found in soils, hydrated ferric oxide, obtained by grinding natural limonite or iron rust into a very fine state, flocculated spontaneously and settled down rapidly after shaking up with water. Yet the fineness of grain was such as would allow it to assume the natant condition, and indeed it did become so if a little ammonia were added to the water. Hydrated alumina, in the form of finely ground bauxite, behaved in a similar manner, and silica after long rubbing in an agate mortar did not yield wholly satisfactory results; even the finest precipitated silica makes a suspension that remains turbid for but a short time. In a truly 'natant' suspension the particles are just defined when enlarged one thousand diameters; they are then seen to be in rapid Brownian motion, but if a trace of flocculating salt be introduced at the edge of the cover-glass as it diffuses into the field of view the particles will be observed to lose their motion and draw together into little clots. These aggregates are however not permanent, but can be at once broken up so as to restore the 'natant' condition by washing away the flocculating salt.

This reversibility distinguishes true flocculation from cases of the clearing of an opalescent liquid by the growth of the suspended particles, such as is seen when a dilute silver solution is precipitated as chloride and the presence of an excess of acid induces the accretion of the very fine particles.

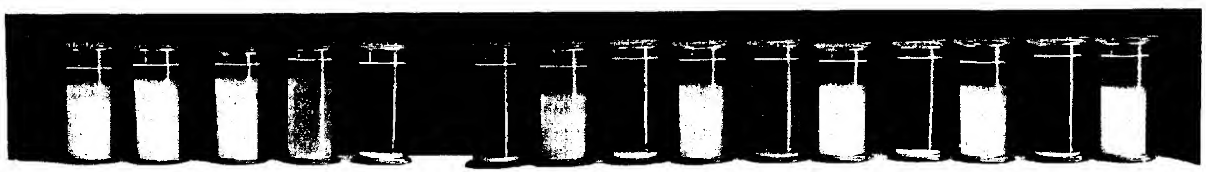
The following experiments illustrate the nature of the changes taking place during flocculation.

1. Up to a certain point, flocculation, as measured by the rapidity of settlement, is proportional to the amount of flocculating salt added. Beyond that limit all solutions flocculate alike.

Suspensions were made up in the usual way by mixing 200 c.c. of water with 10 c.c. of the strong kaolin suspension and a measured quantity of calcium nitrate solution to bring the strength of the liquid to the concentration specified in the second column.

$n/2000$ $n/1000$ $n/500$ Calcium Chloride — $n/2000$ $n/1000$ $n/500$ Calcium Nitrate — $n/2000$ $n/1000$ $n/500$ Calcium Sulphate

I. Comparative flocculating effects of Hydrochloric, Nitric, and Sulphuric Acids (as Calcium Salts).



1 2 3 4 5

II. Acetic Acid.
1. $n/40,000$. 2. $n/20,000$.
3. $n/10,000$. 4. $n/5000$.
5. $n/2500$.

1 2 3 4 5

III. Comparison of acids and their sodium salts at $n/10,000$. In each pair the left hand jar contains acid, the right hand jar its sodium salt.
1. Hydrochloric. 2. Sulphuric. 3. Acetic. 4. Mono-chlor-acetic.
5. Tri-chlor-acetic.

EXPERIMENT I. *Calcium nitrate.*

No.	Strength of solution, fractions of normal	
1	100,000	After 90 hours, not clear but forming layers.
2	40,000	" " clearing a little.
3	20,000	Not quite clear in 90 hours.
4	10,000	Clear in 48 hours.
5	4,000	Showed flocculation in 4 hours, clear in 9 hours.
6	2,000	" " "
7	1,000	After 4 hours nearly clear.
8	400	" "
9	200	" "
10	100	" "
11	40	" "
12	20	" "

In this case a concentration of $n/1000$ seems to be about the limit for the amount of kaolin used, increase of concentration beyond that point does not cause any quicker settlement. This experiment may be compared with a parallel series where sodium chloride replaced the calcium nitrate.

EXPERIMENT II. *Sodium chloride.*

No.	Strength of solution, fractions of normal	
1	100,000	No change after 70 hours.
2	40,000	
3	20,000	Clearing in layers after 70 hours.
4	10,000	" " "
5	4,000	Clear after 48 hours.
6	2,000	Flocculating but not clear after 9 hours.
7	1,000	Clear after 9 hours.
8	400	After 4 hours nearly clear.
9	200	" "
10	100	" "

Here the limit may be taken as $n/400$ sodium chloride, as compared with $n/1000$ calcium nitrate, all the suspensions containing the two salts in these ratios pursuing a parallel course.

The results with calcium nitrate and sodium chloride were typical of those obtained with a number of other salts, the only variation being the limit of concentration above which complete flocculation set in. Of course some salts will not induce flocculation at all, a fact which will be considered later.

No evidence was obtained of reversal effects, such as a substance ceasing to flocculate when its concentration was increased above a certain strength, or of the existence of successive maximal and minimal points of flocculation as described by Joly (*loc. cit.*), though experiments were made with sodium nitrate up to concentrations of $2n$ or 17 per cent. of the salt.

2. The reaction between the flocculated substance and the flocculant is a quantitative one.

The following experiment will illustrate this point; the amount of kaolin in the suspensions was varied, being 1, 2, 4, and 8 times the normal respectively. Similarly the amount of the flocculating salt, calcium nitrate, was varied so as to obtain three series of jars containing the same ratio of kaolin to salt, the water being varied to make up the same bulk in each case.

EXPERIMENT III.

No.	c.c. of kaolin suspension	c.c. of $n/100$ calcium nitrate added	Ratio of kaolin to calcium nitrate
1	1	1	1
2	2	1	2
3	4	1	4
4	8	1	8
5	2	2	1
6	4	2	2
7	8	2	4
8	4	4	1
9	8	4	2
10	8	8	1

Under these conditions 1, 2, 3, 4 cleared in succession though they all contained the same concentration of calcium nitrate. Numbers 1, 5, 8 and 10, however, cleared approximately together, as afterwards did 2, 6, and 9, and still later 3 and 7. Suspensions containing the same ratio of kaolin to calcium nitrate cleared simultaneously, whatever the absolute amounts of the substances that were present in the liquid. In other words, a certain amount of salt is required to flocculate a given amount of kaolin, a conclusion which would also follow from the existence of a limit of concentration required to bring about flocculation in a given kaolin suspension, as described in the previous section. To carry out this experiment successfully it is of course necessary not to overpass this limit, otherwise all the suspensions will settle at the same rate. Again it is necessary to work at great dilutions and with small quantities of kaolin, because the relationship becomes obscured by the tendency of the higher concentrations of kaolin to clear more rapidly. When the flocculated kaolin is in any quantity it mats together, falls quickly, and to some extent clears the liquid behind it. In other words, a dense turbid liquid clears more effectually than a thin one, and this is true whether it is flocculated or not. But with care the quantitative relationship can be verified for various salts.

3. The process of flocculation does not appear to be accompanied by any removal of the salt from solution by the flocculated kaolin

(adsorption or laking out), nor by any selective absorption of base from the salt, so as to give rise to acidity in the liquid after flocculation had taken place. Picton and Linder (*loc. cit.*) found that the flocculation of arsenious sulphide by barium chloride was accompanied by a withdrawal of barium from solution, so that the resulting medium was acid. Working with kaolin no such acidity could be detected, and other experiments in the Rothamsted Laboratory (see Hall and Gimingham, *Trans. Chem. Soc.*, 91, 1907, 677) show that soluble salts such as cause flocculation merely interchange bases with the complex hydrated double silicates which make up kaolin.

Experiments were also made to ascertain if a change in conductivity accompanied the process of flocculation, as follows:—

A cylinder of Jena glass holding about 300 c.c. was immersed in a constant temperature bath with glass sides. A pair of platinum electrodes, held rigid by tubes (of Jena glass) containing the leads and suitable cross-pieces above and below, were completely immersed in the cylinder, which also contained a stirrer of silver. Usually the experiment began by measuring the conductivity of a measured volume of pure water in the cylinder, and determining the increase brought about by the addition of 10 c.c. of a solution of flocculating salt kept in the same bath. The required amount of kaolin suspension, also kept in the same bath, was then run in and the change in conductivity determined again. A previous blank experiment gave the conductivity of the kaolin suspension when diffused alone in the given volume of pure water.

Two of the experiments may be given, conductivities being expressed in reciprocal ohms per c.c.

EXPERIMENT IV. *Barium chloride* ($n/350$) *and kaolin* (0·2 *gram*).

The water used had a conductivity	$=2{\cdot}72 \times 10^{-6}$
On addition of the kaolin suspension it became	$=25{\cdot}35 \times 10^{-6}$
Increase due to the kaolin	$=22{\cdot}63 \times 10^{-6}$
On further addition of barium chloride the conductivity of the whole became	$=352{\cdot}8 \times 10^{-6}$
Increase due to the barium chloride	$=327{\cdot}45$
Starting the reverse way—	
Water	$=2{\cdot}99 \times 10^{-6}$
After the same amount of barium chloride had been added	$=331{\cdot}9 \times 10^{-6}$
Increase due to the barium chloride	$=328{\cdot}91 \times 10^{-6}$
On a further addition of kaolin	$=341{\cdot}5 \times 10^{-6}$
Increase due to the kaolin	$=9{\cdot}6 \times 10^{-6}$
Summarising—	
Increase of conductivity caused by barium chloride in water only ...	$=328{\cdot}91$
Increase of conductivity caused by barium chloride in kaolin suspension	$=327{\cdot}45$
Increase of conductivity caused by kaolin in water only	$=22{\cdot}63$
Increase of conductivity caused by kaolin in barium chloride solution	$=9{\cdot}6$

Thus in neither case did the flocculation result in lowering the conductivity of the salt solution, though when the kaolin was added to the barium chloride the increase in conductivity was not quite so great as would be expected from simply adding the conductivities of the separate constituents together.

EXPERIMENT V. *Aluminium sulphate* ($n/350$) *and kaolin* (0·2 *gram*).

Water alone	$=1{\cdot}35\times10^{-6}$
Water + aluminium sulphate	$=227{\cdot}6\times10^{-6}$
Water, aluminium sulphate, and kaolin	$=247{\cdot}5\times10^{-6}$
Conductivity added by the kaolin	$=19{\cdot}9\times10^{-6}$
Conductivity added by kaolin to pure water	$=22{\cdot}63\times10^{-6}$

EXPERIMENT VI. *Finely powdered natrolite* (0·2 *gram*) *and water.*

Water alone	$=2{\cdot}72\times10^{-6}$
Water and natrolite	$=6{\cdot}61\times10^{-6}$
Increase of conductivity due to natrolite alone	$=3{\cdot}89\times10^{-6}$

EXPERIMENT VII. *Natrolite* (0·2 *gram*) *and barium chloride* ($n/350$).

Barium chloride solution	$=336{\cdot}0\times10^{-6}$
After addition of natrolite	$=329{\cdot}3\times10^{-6}$

EXPERIMENT VIII. *Natrolite* (0·2 *gram*) *and ammonium chloride* ($n/350$).

Ammonium chloride solution	$=390{\cdot}8\times10^{-6}$
After addition of natrolite	$=381{\cdot}3\times10^{-6}$

In the two latter cases the addition and flocculation of natrolite were accompanied by a slight reduction in the conductivity of the solution, but this may be explained by the fact that barium or ammonium in the solution was to some extent replaced by sodium from the natrolite, *i.e.* by an element with a lower specific conductivity at those dilutions employed.

Other experiments were tried, but there was no evidence of any such drop in conductivity as would be occasioned by the removal from solution of any appreciable fraction of the salt.

4. The next stage in the experiments was to ascertain the comparative flocculating powers of a series of salts. The method of work was in all cases the same; varying amounts of the salt under investigation were added to the jars containing suspensions of kaolin made in the usual way, and these were matched against a standard series started at the same time with varying amounts of calcium nitrate as flocculant. It was early found that the flocculating power of the salts of a given metal is not independent of the acid, so that in

the comparisons of the various metals, chlorides had to be tested against chlorides, sulphates against sulphates, and so on.

The following list shows the comparative flocculating power of equi-normal solutions of the various metals tried, when the effect of the acid is eliminated; calcium nitrate being taken as a standard = 10.

H_2SO_4	20	HCl	>20	HNO_3	>20
$Al_2(SO_4)_3$	20				
$CaSO_4$	>5	$CaCl_2$	>10	$Ca(NO_3)_2$	10
$MgSO_4$	<5			$Ba(NO_3)_2$	10
K_2SO_4	<1	KCl	>2	KNO_3	>2
Na_2SO_4	0·5	$NaCl$	>1	$NaNO_3$	<1

The most powerful flocculators are therefore the free acids, though the aluminium salts come very close, possibly because they are so completely hydrolised in solution. The trivalent aluminium is more effective than the divalent elements calcium and magnesium, which in their turn flocculate better than sodium or potassium; but there is no evidence for the ratios 1 : 32 :: 1024 between mono-, di- and trivalent elements, which were found by Picton and Linder and justified on theoretical grounds by Whetham. Moreover the monovalent elements do not agree among themselves, potassium being about twice as effective as sodium, and hydrogen ten times greater still.

It should be remembered that the dilution of the solutions causing flocculation in these experiments is very great, usually about one-thousandth normal, so that the salts must be regarded as completely ionised.

It has already been stated that the flocculating power of a salt depends on the nature of the acid as well as of the base; a number of experiments were made to ascertain the relative order of the three acids —hydrochloric, nitric and sulphuric. The same relation was obtained whether the free acids or their salts were used, the best measurements of the ratios being

Hydrochloric acid	20
Nitric acid	19
Sulphuric acid	13

These ratios are not unlike the relative ionic dissociations of the three acids, as measured by their electrical conductivities, but any theory founded on such an agreement is not borne out by the behaviour of other acids like acetic. Acetic acid proved to be a very effective flocculant, being but little less active than sulphuric acid, 9 as against 13 on the above scale. Substitution of chlorine in the acetic acid made but

little difference, monochloracetic acid being rather more effective than the di- and tri-chloro acids, and all being a little better than acetic acid itself. The range of difference can hardly however be expressed in figures. On the other hand, amid-acetic acid did not flocculate at all.

Of the other acids tried oxalic and tartaric caused flocculation; and may be represented by 2·5 on the scale, oxalic being rather the more effective. Citric acid and phenol did not flocculate at all.

Perhaps the most interesting case is however afforded by the behaviour of the hydrates: it has always been known that the free alkaline hydrates are powerful deflocculators, a trace of ammonia, potash or soda will immediately cause clay particles to assume the 'natant' condition. This is also true of the carbonates and bi-carbonates of the alkalis and of similar salts of weak acids like the borates and the phosphates. Calcium hydrate is however used in practice to flocculate clay, as is shown by the improved tilth resulting from the application of quicklime to clay soils. In this case however the action is complicated by the presence of carbon dioxide, which will on the one hand precipitate the calcium as carbonate, dragging down at the same time the suspended material, and again will give rise to soluble calcium bi-carbonate.

Several determinations were made of the flocculating power of calcium hydrate, care being taken to deprive all the solutions used as far as possible of carbon dioxide and also to keep the suspensions out of contact of the air during their standing. Under these conditions calcium hydrate had a flocculating power of about 3, when calcium nitrate is rated at 10 for comparison; the concentration of the suspension in calcium hydrate being about one-thousandth normal. It will thus be seen that the flocculating effect of calcium hydrate is positive, whereas the hydrates of potassium, sodium, and ammonium give negative effects. Barium hydrate gave a very similar result to calcium hydrate.

It may perhaps be concluded that hydroxyl ions have a negative flocculating action, which is able to overpower the positive action of the potassium, sodium and ammonium ions, but is not equal to the greater positive action of the calcium or barium ions.

When calcium bi-carbonate was tried it proved a very effective flocculator, being a little better than equivalent solutions of calcium nitrate, though a numerical value could not be given to the superiority. Nor could this be attributed to the excess of carbon dioxide, for

measurements of a solution of free carbon dioxide only give the low value of 0·5 for carbon dioxide.

5. A few experiments were tried with other materials than kaolin. Bauxite and limonite respectively were ground fine in an agate mortar, and further reduced by wet grinding in an improvised ball-mill for a day or two. Precipitated silica was also prepared and used after igniting and grinding. Neither bauxite nor limonite would assume the 'natant' condition in pure water; they flocculated and settled immediately. The presence of alkali in concentrations of $n/2000$ to $n/500$ however caused them to remain suspended; sulphuric acid flocculated, but aluminium sulphate at the same concentrations caused the bauxite to remain suspended. In a second series the bauxite with aluminium sulphate again held up better than the check with pure water, but magnesium sulphate tried at the same time permitted of flocculation like the pure water. A small sample of allophane, $Al_2(HO)_2SiO_4 + xH_2O$, was scraped off and reduced to a fine powder; this also would not assume the natant condition in pure water, though it would remain suspended when a trace of free alkali was added.

The experiments with these bodies were abandoned because of the impossibility of obtaining true suspensions in water alone.

With ignited silica there was no difference between the suspensions in pure water and those containing either acid or alkali; flocculation could be brought about by aluminium sulphate, but it was difficult to make satisfactory suspensions.

The authors have failed to find any satisfactory theory that embraces the whole of the observed facts.

The electrical theory developed by Whetham, depending upon the discharge of the suspended particles by the free ions, would seem to fail, because

(1) The flocculation depends upon the ratio of amounts of flocculating material and flocculant, and not merely on the concentration of the flocculant.

(2) The different acids and the salts of different acids show great variations in their flocculating power, nor are these variations dependent on the degree to which ionisation takes place. Acetic acid and the acetates for example have much the same value as sulphuric acid and the sulphates, and chlorinating the acetic acid has little effect on the result.

(3) The ratio between the flocculating power of mono-, di- and trivalent metals is far from that expected by the theory.

(4) No change takes place in the conductivity of the solution during and after flocculation.

The electrical theory sketched by Joly is similarly not justified by the facts.

Again flocculation cannot depend upon the hydrolysis of the salts employed and the action of the free acid, except perhaps in the case of the aluminium salts. Hydrolysis alone would not explain the effectiveness of such salts as calcium chloride which are but slightly hydrolised, nor the high position of the acetates, nor the fact that the chloracetates possess much the same value as the acetates.

The authors also consider that the conductivity experiments and the quantitative measurements with stronger solutions already referred to must dismiss any theory founded on the selective precipitation of the base of the flocculant on to the suspended particles and a resulting 'laking out.'

Nor can any theory be built up on an hypothesis of preliminary chemical action between the salt and the particles (though the salts in question do act upon kaolin), accompanied by aggregation. Such an explanation is sufficiently negatived by the fact that the action is reversible; the flocculated material can be suspended afresh in pure water when the salt has been washed away.

It was thought that the preliminary chemical action might induce some change in the surface tension existing between the solid particles and the solution; this however is not a sufficient hypothesis as the following experiment shows. Kaolin was flocculated by 1/10,000 normal ammonium chloride solution, washed free from salt, and re-suspended in pure water. On adding ammonium chloride to again bring up the solution to 1/10,000 normal the kaolin was flocculated afresh. No new chemical action could have taken place, because on the first occasion the kaolin would have completed its reaction with the ammonium chloride of that concentration so that no further change would take place on a second contact with another solution of the same strength.

Before any theory of flocculation can be reached it is probably necessary to determine the conditions which must be satisfied before a given substance will assume the 'natant' state. While size is of course a factor, for particles above about 0·004 mm. will not remain suspended for any length of time, chemical composition also comes in to determine whether the particles below this limit will possess a Brownian motion and remain apart instead of aggregating when

suspended in water. Of the substances examined, only kaolin natrolite and the various clays, which may be regarded as impure kaolins, would become natant; hydrated alumina, hydrated ferric oxide, silica, and even allophane, another hydrated silicate of alumina, fall rapidly and completely from suspension to form a matted deposit at the bottom of the vessel. Furthermore it can be shown that it is not the zeolitic character of the kaolin &c. that confers the natant character. A sample of kaolin was ignited for some time at a low red heat, more than sufficient to destroy any zeolitic compounds; this sample was then graded by suspension in water like the original kaolin and a fraction separated that would remain suspended for 24 hours. A number of suspensions were then made up containing equal dilutions of ignited and unignited kaolin respectively, and various amounts of calcium nitrate added to induce flocculation; the ignited kaolin assumed a true 'natant' condition, but was more readily flocculated than the unignited kaolin. The only feature that seems to distinguish the natant from the non-natant bodies, is that the former—kaolin and natrolite—are essentially double salts of an alkaline metal which give rise to a trace of free soluble alkali when they are mixed with water. Both kaolin and natrolite contain alkaline metals, and fresh mineral specimens when ground in an agate mortar with pure water will gradually blue a strip of red litmus paper immersed in the thin paste when it is allowed to dry spontaneously. On the other hand the specimen of allophane used seemed to be free from the alkali metals, as also are limonite, bauxite and the silica used; these latter substances would only become natant when free alkaline hydrates were added to the suspensions.

If then the natant condition is dependent on the presence of traces of free alkali derived from the partial hydrolysis of the suspended material, it is clear that the free acids should be the best flocculators; it is also reasonable to suppose that the presence of a salt, which would react in the way of double decomposition with the part of the material that would be hydrolised by pure water, would also tend to suppress any free alkaline hydrates. Again the general quantitative relationship between suspended material and flocculant would also follow; even the departure from this rule in that a concentrated suspension requires a smaller proportion of flocculant than a dilute one, can be explained by assuming that the amount of hydrolysis of the natant material would be greater when it was in contact with a larger bulk of water.

Beyond this point, that the natant condition is dependent upon the presence of free alkaline hydrates and that flocculation ensues when these are neutralised or driven back into combination with the suspended solid, the authors prefer to attempt to put forward no further theory, but merely to record a series of observations and measurements that are critical of the theories already advanced, in the hope that they may afford material to induce some physicist to take up the question afresh. It would appear to be necessary first to arrive at an explanation of Brownian motion.

THE EFFECT OF FUNGICIDES UPON THE ASSIMILATION OF CARBON DIOXIDE BY GREEN LEAVES.

By ARTHUR AMOS, B.A.

In some of the earlier experiments in which Bordeaux Mixture was used as a fungicide, it has happened that neither the part sprayed nor the control has suffered from disease at all; yet it has been recorded that the sprayed part has continued green for a longer period and has produced a larger crop.

Again "Flowers of Sulphur" is commonly blown on to the hop plant by hop growers in Kent shortly before picking, the object being to cause the hops to retain their green colour for a longer period.

It might be supposed therefore that both Bordeaux Mixture and Flowers of Sulphur, when applied to a green leaf, may increase the amount of carbon dioxide assimilation independently of any possible fungicidal action.

Frank and Krüger (*D. Landw. Gesell.* 1894, 2) state that both assimilation and transpiration are increased in leaves treated with Bordeaux mixture, owing to the stimulating action of the copper salts.

On the other hand more recent experiments by Ewert (*Landw. Jahr.* xxxiv. (1905), 233) and others have shown that plants sprayed with Bordeaux Mixture gave a diminished crop, although they retained their green colour for a longer period than the unsprayed.

The following experiments were devised to ascertain whether the assimilation of carbon dioxide was affected in any way by the application of Bordeaux Mixture or Flowers of Sulphur, and whether any stimulus effect could be demonstrated.

Method employed.

In each experiment a pair of leaves on the same plant were selected; where possible, opposite leaves on the same stem; the pair were selected as nearly as possible identical in age, shape, and size.

The leaves remained attached to the growing plant throughout the experiment; one being used as a control to the other.

In order to determine the assimilatory powers of the leaves the method employed by Brown and Escombe (*Proc. Royal Soc.* B LXXVI. (1905), 30) was used; the leaves were placed separately into glazed cases, in which they were exposed to sunlight, and through which air was drawn; the volume of air and content of CO_2 in the issuing air were then determined, and knowing the original CO_2-content of air, the amount of CO_2 assimilated by each leaf could be calculated.

By this means the ratio between the assimilatory powers of the two leaves was obtained; this was twice repeated to ensure accuracy, and then one of the leaves was treated with the fungicide.

The ratio between the assimilatory powers of the two leaves was again determined on three occasions after the application of the fungicide, when any alteration in the ratio may be set down to the application of the fungicide.

The apparatus was that originally used by Brown and Escombe and was kindly lent by Dr Horace Brown; it will be sufficient here to state that the leaves under experiment were simultaneously exposed to the light in their respective cases and that the air-current was drawn over each at as nearly as possible the same rate. For the details of the corrections that have to be made for temperature and pressure, and the titration of the alkaline absorbing solution, Brown and Escombe's paper should be consulted. The absolute content of carbon dioxide in the air at the time of each experiment was not determined.

Calculation of Results.

Brown and Escombe[1] have shown that the CO_2-content of the air at the Jodrell laboratory at Kew varies on rare occasions, and only during thick fog, between the limits of 2·8 and 3·2 parts per 10,000; with a mean to 2·9 parts per 10,000 in 91 experiments.

During the experiments the CO_2-content of the air was occasionally determined, and this always fell well within the above-mentioned limits.

This mean amount, 2·9 parts per 10,000, was assumed to be the CO_2-content of the air entering the leaf-cases; and since it was not the absolute CO_2-assimilation, but merely the relative assimilation between

[1] *Proc. Roy. Soc.* Vol. B LXXVI. 1905, p. 118.

two leaves that was required, this assumption can only cause an insignificant error.

On this assumption the amount of CO_2 absorbed per sq. decimeter of leaf area per hour was then calculated; let it be x cubic centimeters.

Now the mean CO_2-content of the air in contact with the leaf in the case is not the CO_2-content of the outside air, but the mean between the CO_2-contents of the entering and issuing air; this mean value is calculated, let it be y parts per 10,000; x then represents the amount of CO_2 absorbed per sq. dcm. of leaf area per hour from air containing y parts CO_2 per 10,000.

Brown and Escombe[1] have shown that the rate of assimilation of CO_2 by green leaves is proportional to the CO_2-content of the air, when the CO_2-content of the air is of the same order as 2·9 parts per 10,000.

In order to make the results comparable they are all calculated to show the amount of CO_2, which would have been assimilated from air containing 2·9 parts per 10,000; *e.g.* in the above case, the leaf would have assimilated $x \times \frac{2{\cdot}9}{y}$ c.c. CO_2 per sq. dcm. per hr., if the mean CO_2-content of the air surrounding the leaf was 2·9 parts per 10,000.

In this way the assimilatory powers of the two leaves under experiment were calculated, and the ratio between these numbers gives a ratio between the assimilatory efficiency of the two leaves.

SERIES I.

After a few preliminary trials to see that the whole apparatus was in working order, the real experiment was begun on June 27th.

In this case the effect of Bordeaux Mixture was tried upon the leaves of the hop.

Early in the spring a hop-root was planted just outside the laboratory window, and the shoots from this were trained upon strings so that, when required, the stems and leaves could be brought into any desired position without injury to the plant.

On June 27th one of the stems was placed upon a bench outside the laboratory window; two opposite leaves were selected, and put into two leaf cases placed side by side upon the bench, and the moveable glass plates cemented in position in each case with soft wax.

[1] *Proc. Roy. Soc.* Vol. LXX. 1902, p. 397.

As soon as the glass plates were fixed in position, a steady stream of air, which passed through rubber tubes from the leaf cases outside to the absorption apparatus within the laboratory, was started, and continued for six hours or more, direct sun being screened from the leaves by a thin linen sheet stretched above.

At the end of this time the amounts of CO_2 absorbed by the caustic soda in the Reisets[1] were estimated, and the absorption of CO_2 by the leaves calculated as previously explained.

On July 3rd and 4th the absorption of CO_2 by the two leaves was again determined under normal conditions.

Then, after the trial on July 4th, Bordeaux Mixture was applied to leaf *B* by gently moistening both the upper and lower surfaces with a sponge soaked in this fungicide.

On July 5th, 6th, and 7th the absorption of CO_2 by the two leaves was determined, and again after an interval of about three weeks on July 26th and 27th.

Table I. contains the results of these experiments; in the first column is the date upon which the experiment was made; the second column gives the volumes of CO_2 absorbed per square decimeter of leaf surface per hour by leaf *A*, the control leaf; the third column gives the volumes of CO_2 absorbed per square decimeter of leaf surface per hour by leaf *B*, which was treated with Bordeaux Mixture on July 4th; the fourth column gives the duration of each experiment; and the fifth column gives the ratio between the figures in columns 2 and 3, and expresses a ratio between the assimilatory powers of the two leaves.

Dealing in the first place with the experiments on June 27th, July 3rd and 4th, it will be noticed that the figure, indicating the volume of CO_2 absorbed by each leaf, varied from day to day; this is due to two factors, firstly to the size of the stomatal openings, which in turn are dependent on a variety of causes, and secondly to the CO_2-content of the air.

Since, however, these factors affect the assimilation of each leaf to the same extent, the ratio between the amounts of CO_2 assimilated by each leaf is not affected by them; and in the last column of the table it is seen that this ratio is fairly constant, varying from 1 : 1·228 to 1 : 1·141, and giving a mean ratio of 1 : 1·178.

One would naturally suppose that this ratio would approximate to 1 : 1 and the fact that in this case it does not do so can only be explained by supposing that leaf *B* was originally more efficient than leaf *A*.

[1] See Amos. This *Journal*, vol. I. 322.

Coming now to the second part of the table, in which leaf *B* ha been coppered, it is seen at once that the assimilation of the coppered leaf *B* had diminished in comparison with that of the untreated leaf *A*, and that the mean of the ratios between the amounts of CO_2 assimilated by leaf *A* to *B* had fallen from 1 : 1·178 (ratio when both leaves untreated) to 1 : 1·047 (ratio when leaf *B* is coppered).

The application of the Bordeaux Mixture had thus reduced assimilation.

TABLE I.

Effect of Bordeaux Mixture on the assimilation of the Hop-leaf.

Date	No. of c.c. CO_2 absorbed per sq. dcm. leaf surface per hour by leaf *A*	No. of c.c. CO_2 absorbed per sq. dcm. leaf surface per hour by leaf *B*	Duration of experiment hrs. min.	Ratio of CO_2 absorbed per sq. dcm. per hour by *A* to *B*
June 27th	2·42	2·97	6 0	1 : 1·228
July 3rd	2·22	2·59	6 0	1 : 1·165
July 4th	2·06	2·35	6 30	1 : 1·141
				Mean 1 : 1·178
	On July 4th leaf *B* was coppered			
July 5th	3·04	3·14	8 0	1 : 1·035
July 6th	2·79	3·14	8 0	1 : 1·125
July 7th	2·37	2·33	8 30	1 : ·980
				Mean 1 : 1·047
	After an interval of 3 weeks.			
July 26th	1·22	1·46	6 0	1 : 1·198
July 27th	1·58	1·88	6 15	1 : 1·190
				Mean 1 : 1·194

Area of leaf $A = 1·262$ sq. dcm. Area of leaf $B = 1·260$ sq. dcm.

It was thought [because of the statements that plants which have been sprayed with Bordeaux Mixture remain green longer than untreated plants] that perhaps, at a still later stage, the coppered leaf *B* would surpass its control leaf *A* in assimilation.

The results of the experiments on July 26th and 27th (when both leaves were beginning to show signs of age) indicate that the assimilatory ratio had returned to about its original value: thus showing that the deleterious effects of the application of Bordeaux Mixture had passed away.

It must however be noticed that the assimilatory powers of both leaves had then dropped to nearly half their original value.

The leaves, shortly after this, began to turn brown, and the sprayed leaf did not keep green longer than the untreated one.

Series II.

Bordeaux Mixture on the Vine.

In this series the leaves of a grape-vine were used; the vine was planted in a large flower-pot, and the plant consisted of a central axis about one foot long, growing from which were five young branches about four feet long at the time of the experiment.

The vine was placed in an unheated green-house in the spring, and the leaves were thus well developed and not bruised.

When required, the vine and pot were arranged outside the laboratory window, so that the stems and leaves could be placed horizontally on the bench.

The vine has alternate leaves, so another device was employed to obtain leaves of equal size and age. Two of the branches from the main axis grew very uniformly and the 7th leaf on each began to unfold about the same time; these leaves, when developed, appeared to the eye equal in all respects, and were selected for these experiments; the assimilatory powers of these two leaves were determined as in Series I. three times before the application of the Bordeaux Mixture.

The Bordeaux Mixture was applied on Aug. 1st in this case by means of a tiny syringe, since it was thought that the application by means of the sponge might damage the leaf.

The assimilatory powers were again determined three times, and then after an interval of 10 days twice more.

Table II. shows the results of this series of experiments, and is arranged exactly as Table I.; the results in this case show still more clearly the effect of the Bordeaux Mixture in diminishing assimilation.

The table shows that, before the application of the Bordeaux Mixture, the assimilatory powers of the two leaves were almost identical, the ratio between them being 1 : 1·02.

After the application of the Bordeaux Mixture to leaf *B*, the assimilatory power of *B* compared with the control *A* was depressed by about $\frac{1}{5}$, the ratio now being 1 : ·79.

TABLE II.

Effect of Bordeaux Mixture on the assimilation of the Vine-leaf.

Date	No. of c.c. CO_2 absorbed per sq. dcm. leaf surface per hour by leaf *A*	No. of c.c. CO_2 absorbed per sq. dcm. leaf surface per hour by leaf *B*	Duration of experiment hrs.	min.	Ratio of CO_2 absorbed per sq. dcm. per hour by *A* to *B*
July 28th	2·28	2·47	8	25	1 : 1·08
July 29th	1·87	1·86	7	30	1 : ·99
July 31st	1·86	1·84	6	0	1 : ·99
					Mean 1 : 1·02
	On Aug. 1st leaf *B* was coppered.				
Aug. 4th	1·56	1·17	7	0	1 : ·75
Aug. 5th	1·72	1·43	4	45	1 : ·83
Aug. 10th	1·97	1·57	5	45	1 : ·79
					Mean 1 : ·79
Aug. 18th	2·17	2·08	6	50	1 : 1·04
Aug. 20th	1·78	1·75	5	0	1 : 1·02
					Mean 1 : 1·03

Area of leaf $A = 1·395$ sq. decimeters. Area of leaf $B = 1·335$ sq. decimeters.

It is again noticeable that this depressing effect of the Bordeaux Mixture passes off after a time, and on Aug. 18th and 20th the assimilatory power of leaf *B* had risen to its original value, the ratio between *A* and *B* now being 1 : 1·03.

During this experiment the leaves grew somewhat and were still quite vigorous and green at the end; it would have been interesting to have continued this experiment longer, but this was unfortunately impossible.

SERIES III.

Bordeaux Mixture on the Jerusalem Artichoke.

In the third series the leaves of an artichoke were employed; artichoke plants, growing in the open ground, were transplanted in June into large flower-pots; at the time of the experiment they were about five feet high and growing vigorously.

During the experiments the plants were propped up on the bench as in the case of the vine.

The leaves of the artichoke are spirally arranged, but grow very thickly on the stem, so that it was quite easy to obtain two leaves on opposite sides of the stem, which were approximately equal in size and age.

Two such leaves were selected, and the assimilatory powers of each determined as in the previous series, firstly, when both were normal, secondly, when one leaf was coppered, and thirdly, a week after the application of the Bordeaux Mixture.

Table III. shows the same general results as the two preceding ones; the initial assimilatory power of the two leaves was nearly equal; after the application of Bordeaux Mixture to leaf *B* the assimilation of this leaf compared with the control leaf *A* was considerably diminished; the ratio between the assimilatory powers of *A* and *B* being 1 : ·84.

On Aug. 21st, eight days after the spraying, the amounts of CO_2 assimilated per sq. dcm. per hour had fallen considerably; this was due to the fact that the leaves, which in the case of the artichoke are comparatively short-lived, were beginning to show signs of age; further, as in the case of Series I. and II., the effect of the Bordeaux Mixture had diminished, and the assimilatory power of *B* compared to *A* had nearly regained its former value; the ratio between *A* and *B* being now 1 : ·93.

TABLE III.

Effect of Bordeaux Mixture on the assimilation of the Jerusalem Artichoke leaf.

Date	No. of c.c. CO_2 absorbed per sq. dcm. leaf surface per hour by leaf *A*	No. of c.c. CO_2 absorbed per sq. dcm. leaf surface per hour by leaf *B*	Duration of experiment		Ratio of CO_2 absorbed per sq. dcm. per hour by *A* to *B*
			hrs.	min.	
Aug. 9th	2·26	2·10	6	50	1: ·93
Aug. 11th	2·84	2·97	5	30	1:1·05
Aug. 12th	2·50	2·42	5	0	1: ·96
					Mean 1: ·98
	On Aug. 13th leaf *B* was coppered.				
Aug. 14th	2·57	2·08	5	30	1: ·81
Aug. 15th	2·53	2·22	6	30	1: ·87
					Mean 1: ·84
Aug. 21st	1·69	1·58	5	0	1: ·93

Area of leaf $A = 2·221$ sq. decimeters. Area of leaf $B = 2·241$ sq. decimeters.

SERIES IV.

Flowers of Sulphur on the Jerusalem Artichoke.

In this series the same procedure was followed as before; after the assimilatory power of the two leaves had been determined on two days, leaf *B* was dusted on both surfaces with flowers of sulphur, and then the assimilatory power of the two leaves was again determined.

It was found that the sulphur produced no effect upon the assimilatory power of the leaf; the mean of the ratios of the assimilatory powers before the application being 1 : ·94 and after 1 : ·96.

TABLE IV.

Effect of Sulphur on the assimilation of the Jerusalem Artichoke leaf.

Date	No. of c.c. CO_2 absorbed per sq. dcm. leaf surface per hour by leaf *A*	No. of c.c. CO_2 absorbed per sq. dcm. leaf surface per hour by leaf *B*	Duration of experiment hrs. min.	Ratio of CO_2 absorbed per sq. dcm. per hour by *A* to *B*
Aug. 16th	2·50	2·42	6 0	1 : ·96
Aug. 17th	2·42	2·23	5 30	1 : ·92
				Mean 1 : ·94
On Aug. 19th leaf *B* was dusted with sulphur.				
Aug. 21st	2·35	2·29	4 0	1 : ·98
Aug. 22nd	2·91	2·67	5 30	1 : ·92
				Mean 1 : ·96

Area of leaf $A = 1{\cdot}580$ sq. decimeters. Area of leaf $B = 1{\cdot}530$ sq. decimeters.

Appended is a table showing the relative assimilatory powers of leaves used by Brown and Escombe and others used by the author.

In both cases the assimilatory power has been calculated for air containing 2·9 parts per 10,000.

TABLE V.

Date and Experimenter		Plant used	CO_2 absorbed per sq. dcm. of leaf per hr.
25/8/98	Brown and Escombe	Helianthus annuus	4·07
4/9/00	" "	Tropæolum majus	1·70
31/8/99	" "	Catalpa bignonioides	5·28
26/6/00	" "	Petasites albus	2·36
3/7/00	" "	Polygonum Weyrielii	2·35
27/6/05	Amos	Humulus lupulus	2·42 and 2·97
28/8/05	"	Vitis vinifera	2·28 and 2·47
9/8/05	"	Helianthus tuberosus	2·26 and 2·10

Conclusions.

The results of the experiments show that the application of Bordeaux Mixture to the leaves of a plant diminishes the assimilation of CO_2 by these leaves for a time; after a time this effect passes off both in cases where the leaves begin to age as in Series I. and III. and also whilst the leaves still keep vigorous as in Series II.

It seems probable that the stomata are partially blocked up by the Bordeaux Mixture, and that consequently less air diffuses into the intercellular spaces of the leaf and less CO_2 therefore comes in contact with the absorption surface.

This is supported by the observations of Schander[1], who found that the application of Bordeaux Mixture diminished transpiration.

The experiments were carried out at the Laboratory of the Lawes Agricultural Trust at Rothamsted, to whom my best thanks are due.

I am also very deeply indebted to Dr Horace Brown, F.R.S., and to Mr A. D. Hall, M.A., for much advice and assistance, and to the former also for the use of his apparatus.

[1] *Land. Jahr.* XXXIII. 1904, 517.

THE CHEMISTRY OF STRENGTH OF WHEAT FLOUR.

By T. B. WOOD, M.A.

Drapers Professor of Agriculture in the University of Cambridge.

Part II. The Shape of the Loaf.

Before proceeding to discuss the immediate subject of this communication, it may be well to recapitulate shortly the views on the general question of the meaning of strength of flours which I expressed in the last number of this journal. It may perhaps be remembered that I suggested that strength, as defined by Humphries and Biffen, to be the capacity of making large well-piled loaves, must be a complex of at least two factors. One of these factors, that which regulates the size of the loaf, I showed to be the power of continuing to evolve carbon dioxide gas throughout the later stages of dough fermentation. I described how to measure this property by incubating in a bottle at 40° C. a mixture of 20 gms. flour, 20 c.c. water, and ½ gm. yeast, the bottle being connected to a gas measuring apparatus, and the volume of gas given off being read from time to time. A number of experimental figures were given, which showed that the size of the loaf which a flour could make, was directly connected with the rate at which it gave off gas in the later stages of dough fermentation, at the time when it was ready for the oven.

The other factor of strength, that which decides the shape of the loaf, I tentatively ascribed to the soluble salts present in the flour. Since then I have been able to work out this line much more fully, and my results are sufficiently advanced to enable me to suggest what appears to be a possible, or perhaps I may even say, a probable, explanation of this factor.

For the sake of clearness it may be well to again recapitulate. Recent work has shown that neither total nitrogen, nor total gliadin,

nor ratio of gliadin nitrogen to total nitrogen, can be taken as a satisfactory index of the baking value of a flour. It seemed to me therefore that only two possibilities remained. The undoubted difference between the properties of the gluten of strong and weak flours might be due, either to some fundamental difference in their chemical composition more deep-seated than that shown by the proportion of the gluten dissolved by alcohol of certain strength, which is the essence of gliadin determinations, or on the other hand to purely physical causes. I therefore prepared samples of gliadin, as described by Osborne and Harris[1], from a number of flours differing widely in baking properties, and submitted them to hydrolysis, by boiling for eight hours with concentrated hydrochloric acid. The percentage of amide nitrogen in each was then determined by distilling with magnesia, and titrating the ammonia in the distillate. The percentage of amide nitrogen in the samples of gliadin was found to be the same for flours of all strengths from 95 to 40. On this evidence I concluded that the gliadins of strong and weak flours were identical. The identity of the glutenin of the same flours was then established in a similar manner, and the next step was to turn to the physical properties.

Much light has recently been thrown on the physical properties of colloids, and it has been shown among other things that the physical properties of such substances depend to a great extent on their surroundings, that in fact it is almost impossible to define their properties without defining the conditions under which they exist. The work of Hardy[2] and that of Picton and Linder[3] is particularly interesting in this connexion, since it shows how the state of aggregation of a colloid is modified by the concentration of acid, alkali, or salt, in the solution with which it is in contact.

It seemed therefore worth while to determine the acidity, and the amount of soluble salts, in a number of flours of widely different baking properties. The results of some of these measurements were given in my last paper, already referred to, and it was pointed out how widely they varied, and how difficult it was to correlate their variations with baking properties. Thus the highest and lowest acidities were found in flours having the same bakers' marks, and there was no apparent connexion between the percentage of soluble ash and the bakers' marks, though there appeared to be some relation between bakers' marks and the ratio of soluble ash to total nitrogen. A second

[1] *J. Amer. Chem. Soc.* 1903, 323 and *Proteids of the Wheat Kernel.* Pub. Carnegie Inst. Washington, No. 84.

[2] *Proc. Roy. Soc.* LXVI. 95 and 110. [3] *Trans. Chem. Soc.* 1892, 148 and 1895, 63.

series of determinations did not make these relations more apparent, and it was at this stage of the investigation that Mr W. B. Hardy suggested that I should try to find some connexion between the properties of gluten and the composition of its surroundings by observing how its properties changed when it was immersed in solutions of varying concentration.

Accordingly a quantity of gluten was prepared from ordinary household flour, and small bits of it were immersed in solutions of which at first the acidity only was varied, the acid used being hydrochloric. After many trials the following method of experimenting was devised, and found to answer extremely well. A large number of small beakers were each marked at 80 c.c. Normal hydrochloric acid was then run in from a burette in sufficient quantity to make the required strength when diluted to the 80 c.c. mark. A small string of gluten about two inches long and as thick as a pencil was then pulled off the large lump and hung by its middle point over a V-shaped glass rod, the tips of the V resting on the edge of the beaker, and the gluten being immersed in the solution. When a mineral acid was used no other antiseptic was necessary. In all other cases the solutions were made up with water which had been shaken with toluene, and the beakers covered if possible to prevent the toluene from evaporating. Such bits of gluten require from 36 to 48 hours to attain equilibrium with the solution in which they are immersed.

Experimenting in this way it was found that gluten immersed in distilled water would retain its coherence for some time, in fact until what were probably bacterial changes intervened or, if the water were repeatedly changed, until all acids and salts had been removed. In very dilute hydrochloric acid however, *e.g.* N/1000, the gluten soon began to disintegrate and lose its coherence, and this change was more rapid as the concentration of the acid was increased up to about N/30. Further increase in concentration slowed down the rate of disintegration, until, at a concentration of N/12, the gluten again became permanently coherent, and much harder and more elastic, and less sticky, than in its original condition. Similar experiments were made with sulphuric, phosphoric, oxalic, acetic, lactic, citric, and tartaric acids. The behaviour of sulphuric, phosphoric, and oxalic acids differed only in degree from that of hydrochloric. Very dilute solutions of each caused the gluten to disintegrate, and strong solutions again produced coherence. The limiting concentration required to cause permanent coherence was, for sulphuric acid N/25, for phosphoric acid 1·75N, for

oxalic N/4. The other acids behaved entirely differently. Dilute solutions produced disintegration, and this became [illegible] more rapid as the solution was made more concentrated. No practicable concentration could be found above which coherence reappeared.

Flour however contains soluble salts as well as acids, and the next step therefore was to try the effect of immersing gluten in dilute solutions of the various acids containing varying proportions of different salts. The first pair tried were hydrochloric acid and sodium chloride, and the experiments were carried out as follows. A number of small beakers were prepared as before. Enough standard hydrochloric acid was run into each to make N/50 solution when the beaker was filled up to the mark. Standard solution of sodium chloride was then added in varying quantity, so as to make say N/1000, N/100, N/10, and the beakers were then filled up to the mark. The bits of gluten, prepared as before, were then immersed in the solution and left for 48 hours. At the end of this time the gluten which was immersed in N/50 acid and N/10 salt solution was firm and coherent, the other two had disintegrated. A second series was then prepared containing N/50 acid and salt solution of varying concentrations between N/100 and N/10. Proceeding in this way it was found that gluten in contact with N/50 hydrochloric acid required the presence of salt of the concentration of about N/12 in order to make it cohere. Further experiments showed that if the acid were either more or less concentrated than N/50, less salt was required to keep the gluten in the coherent condition. A number of measurements of the concentration of salt required to make gluten preserve its coherence in acids of several concentrations between N/1000 and N/12 were made, and the results are plotted in the curve for NaCl in Pl. VI. Fig. 1. In this and all the accompanying curves in Pl. VI. the ordinates represent the concentration of salt in gram equivalents per 1000 litres, the abscissae the concentration of acid on the same scale. The method of working and the appearance of the gluten in the different states are well shown in Pl. V.

Pl. VI. Fig. 1 also shows similar curves for other salts beside sodium chloride. It is noticeable that the curves for the different salts are all of the same type, the chief differences being stated below. Three sodium salts were tried, chloride, sulphate, and phosphate. Of these chloride and phosphate are approximately equal in power of producing coherence, but chloride is more active in combination with more concentrated acid, phosphate with less concentrated acid. Sulphate is much more active than either chloride or phosphate, the ratio

HCl	0	10	10	10	20	20	100
NaCl	0	60	75	90	75	90	0

HCl	0	10	10	20	20	100
Na_2HPO_4	0	18	24	50	70	0

HCl	0	10	10	10	20	20	20	100
Na_2SO_4	0	20	25	40	20	40	60	0

HCl	10	10	10	20	20	40	40	40
$MgSO_4$	10	15	20	20	40	10	15	20

HCl	10	10	20	20	60
$Al_2(SO_4)_3$	8	12	10	20	5

The figures give concentrations in gram-equivalents per 1000 litres.

of their activities being approximately as follows:—chloride or phosphate : sulphate as 2 : 3. Sulphate resembles chloride in being more active with higher concentrations of acid.

The other three curves in Pl. VI. Fig. 1 show the results of similar experiments with the sulphates of sodium, magnesium, and aluminium. Evidently the activity is related in some way to valency, increasing as the valency increases. The ratio of the activity of sodium : magnesium : aluminium is roughly 1 : 2 : 4.

Similar results were obtained by experimenting with other acids. Pl. VI. Fig. 2 gives the curve for sulphuric acid and sodium chloride, Pl. VI. Fig. 3 that for phosphoric acid and sodium chloride, and Fig. 4 that for oxalic acid and sodium chloride. These curves are all of the same type as that for hydrochloric acid and sodium chloride. They differ only in the limits of concentration of acid required to keep the gluten coherent in the absence of salts.

Curves of quite another type are shown in Pl. VI. Fig. 5, the curve for lactic acid and sodium chloride. In this curve the behaviour of lactic acid is well shown. Gluten disintegrates in all strengths of this acid, the rate of disintegration being more rapid the more concentrated the solution. As the concentration of the acid is increased more and more sodium chloride must be added to preserve coherence. In this respect tartaric and citric acids resemble lactic.

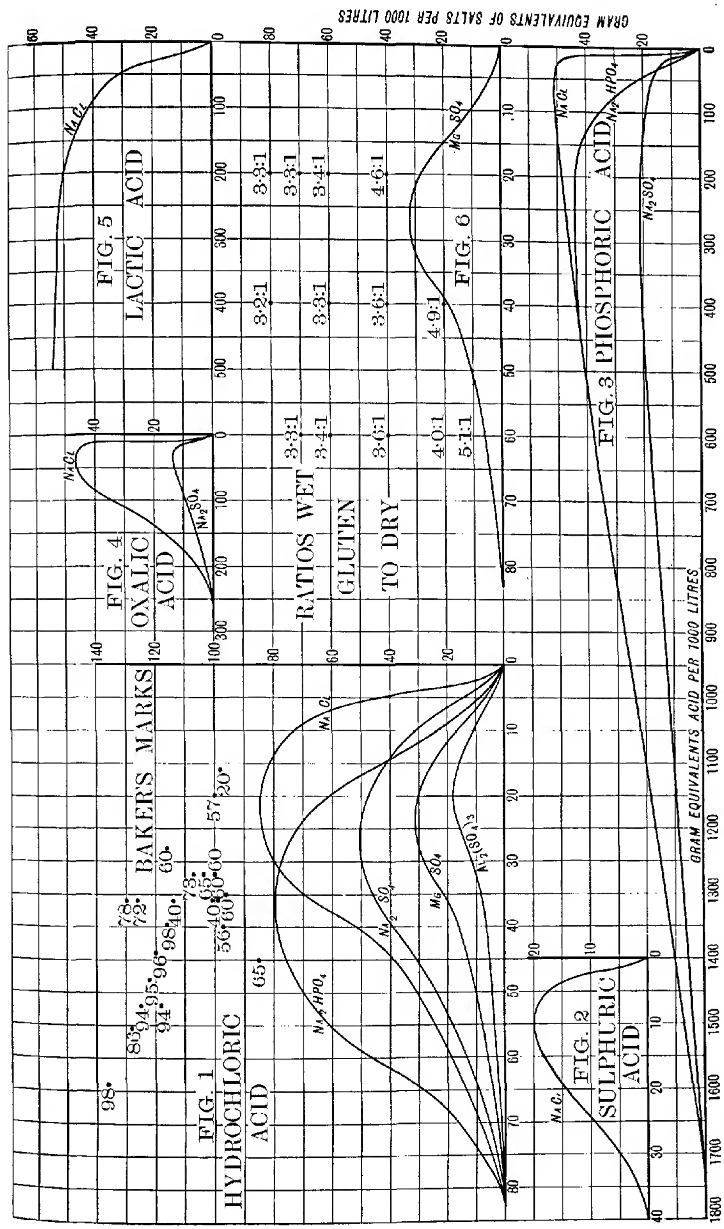
The experiments described above show quite clearly that the physical properties of gluten are entirely altered by changing its surroundings. Thus for concentrations of acid and salt which fall when plotted inside the curves, gluten is in a powdery or flocculent condition, quite devoid of coherence. For concentrations which fall on the curves gluten is just on the point of changing from the flocculent to the coherent condition. For concentrations outside the curves it is coherent.

Another point to notice is that the connexion between the properties of gluten and the acidity and salt content of its surroundings is not one which would become evident by comparing analytical figures with bakers' marks, for the same effect is produced by say, N/1000 HCl and N/100 NaCl, by N/50 HCl and N/10 NaCl, and by N/20 HCl and N/20 NaCl. In other words the amount of soluble salt required to produce a certain degree of coherence at first increases with the acidity up to a maximum and then falls off again. This is at once evident from the shape of the curves in Pl. VI. Figs. 1, 2, 3 and 4, and it probably explains why no one has succeeded in connecting acidity and soluble salt content with baking properties.

It has already been stated that the curves represent the conditions of concentration of acid and salt at which the gluten is just beginning to be coherent. If a bit of gluten suspended from a glass rod in a solution whose concentration is represented by a point on one of the curves is removed from its solution after attaining equilibrium, its coherence is only just sufficient to enable it to bear its own weight. It is far inferior in coherence, toughness and elasticity to a sample of gluten freshly rubbed out from a sample of good flour. It therefore seemed necessary to investigate the change of properties of gluten in contact with solutions whose concentrations are represented by points at varying distances outside the curves. This was done by immersing bits of gluten in such solutions by the method already described, allowing them 48 hours to attain equilibrium, removing them from their solution, leaving them to drain for half-an-hour, and drying them to constant weight in the steam-oven. Proceeding in this way one can readily determine the ratio of the weight of gluten when wet to the weight when dry. For points immediately outside the curves this ratio is found to be approximately 5 : 1. As the concentration of the salt increases, and the point moves away from the curve, the gluten gets continuously drier, and the ratio more nearly approaches that of freshly washed-out gluten. Figures for gluten in contact with hydrochloric acid and magnesium sulphate solution are given in Pl. VI. Fig. 6. They seem to offer an explanation for the well-known difference in water absorbing capacity found in certain flours, and since the toughness of the gluten increases as the water content falls, to connect both water absorption and toughness of gluten with acidity and content of soluble salt.

The experiments above described suggest that the variations in coherence, elasticity, and water content, observed in gluten extracted from different flours, are due rather to varying concentrations of acid and soluble salts in the natural surroundings of the gluten than to any intrinsic difference in the composition of the glutens themselves. These properties must undoubtedly have a direct bearing on the power which some flours possess of making shapely loaves. I suggest therefore that the factor of strength on which the shape of the loaf depends is the relation between the concentrations of acid and soluble salts in the flour.

The correctness of these ideas should be capable of being tested in two ways. The most direct way would be to determine the acidity and soluble salt content of a flour, and to alter one or both by the



GRAM EQUIVALENTS OF SALTS PER 1000 LITRES
GRAM EQUIVALENTS ACID PER 1000 LITRES
FIG. 1
HYDROCHLORIC ACID
BAKER'S MARKS
FIG. 2
SULPHURIC ACID
FIG. 3 PHOSPHORIC ACID
FIG. 4
OXALIC ACID
FIG. 5
LACTIC ACID
FIG. 6
RATIOS WET GLUTEN TO DRY

[illegible] acid, alkali or salt. Treated and untreated portions of the flour would then be submitted to baking tests in order to discover if the treatment had altered the water absorbing capacity or the shape of the loaf. A little consideration will however show that no positive result is likely to be obtained in this way. It has already been stated that a small bit of gluten takes 48 hours to attain equilibrium with any solution in which it may be immersed. Bread is always in the oven in a much shorter time than this after the flour is first moistened. In order therefore to give any added acid, alkali, or salt a chance to modify the gluten, it would have to be added some 40 hours before the doughing was begun, and since it could not be expected to act until moistened, the treated flour would have to be kept moist for that length of time before the yeast was added. Such a proceeding would of course be impracticable, both for mechanical reasons, and because bacterial fermentation would intervene. That portion of the flour which is used for the sponge might possibly be treated with more hope of success, since it is longer in contact with the water.

Another but more indirect way of testing the idea is to determine the acidity and soluble salt content of a number of flours of known baking properties, to calculate from these analytical figures the concentrations of acid and salts as they exist in contact with the gluten in its natural state in each flour, to plot these concentrations side by side with the curves already given, and to see if the baking properties of the flours agree with the position of the points with respect to the curves. Flours of good baking properties should give fairly dry, tough elastic gluten, and the points representing the acidity and salt content of such flours should be situated a considerable distance outside the curves, say in Pl. VI. Fig. 1. Weak flours on the other hand should give sloppy gluten with very little toughness and elasticity, and the points representing the acidity and salt content of such flours should fall only just outside the curves.

The experimental work necessary to make a number of such comparisons looks at first sight quite simple, and will I have no doubt ultimately turn out to be so, consisting simply of making a water extract of the flour under standard conditions, titrating a measured volume of this extract with a dilute standard alkali and phenolphthalein as indicator, and evaporating and igniting a second measured volume. But before the figures so obtained can be used to fix a position on the diagram which will indicate the kind of gluten the flour possesses, several important points must be settled.

The suggestion above made is, that the properties of gluten depend on the concentration of acid and salts, and on the kind of acid and salts, in the solution with which the gluten is in contact. The points which have to be settled therefore are: firstly, the nature of the acid and of the soluble salts contained in flour, and, secondly, the factor to be used to calculate, from the observed acidity and soluble salt content of the flour, the concentration of the solution upon which the properties of the gluten depend.

I am not yet in a position to make definite statements on either of these points. I have not up to the present attempted to investigate the nature of the acid. As regards the salts, I find that good flours of the Fife class contain in their soluble salts a preponderance of phosphate, whilst flours like Rivett contain little phosphate and much chloride. This point will be further investigated as soon as flours of the 1907 crop come to hand, and there should be no difficulty, other than experimental trouble, in settling it.

In the second point the difficulty is rather theoretical than experimental. It is quite simple to determine the percentages in the flour, but it is at present by no means clear how to convert these figures into the required concentrations. Before this can be done it must be decided at what stage the acid and salts influence the gluten so as to impress upon it the physical properties which decide the character of the flour. I take it that this must occur when the endosperm is being formed, at which time the grain contains much more water than when it is ready to grind. What is really required therefore is the concentration of the cell-sap of the grain during the process of endosperm formation. I hope to be able to determine this later, but for the present I have adopted the method of multiplying the percentages in the flour by the arbitrary factor 2, which corresponds to a water content in the endosperm of about 40 per cent. That this is not far from the truth is indicated by the fact that points calculated on this assumption are invariably situated on the diagram (Pl. VI. Fig. 1) in a region where the ratio of wet to dry gluten, which is predicted by the position of the point, agrees approximately with that found by experiment.

Working in this way a number of flours were examined, and the points corresponding to the acidity and salt concentration of the cell-sap of their endosperm are plotted on Pl. VI. Fig. 1. Each point is marked by a dot, to the left of which are printed the bakers' marks of the flour. It will be seen at once that the points corresponding to the

stronger flours fall much further outside the curves than the points corresponding to the weaker flours. Closer agreement than that shown cannot be expected until the debateable points already discussed have been worked out, and a method has been devised for measuring the shape of the loaf as distinguished from strength. The curves in the figure are those for hydrochloric acid and various simple salts. It is obvious that a much better comparison would be possible with curves for mixtures of salts made to imitate the soluble salts of various flours. In considering these figures it must be remembered that the bakers' marks express something like the mean of size and shape of loaf, while the position of a point on the diagram indicates the physical state of the gluten which can only influence one of these factors, the shape of the loaf.

I fully realise that my results are at present only in what may be called a suggestive state. My excuse for publishing them at once is that flours of the 1906 crop are no longer in a fit state to work upon, and several months must elapse before those of the 1907 crop are ready. In the meantime the results at least suggest a new method of investigating many practical problems in which the physical properties of proteid substances form an essential point.

Such a problem presents itself in the manipulation of the curd in cheese making. I suggested to my pupil Mr W. J. Richardson, B.A., that he should carry out some preliminary experiments on this subject. He has found the following method of working most satisfactory, and has obtained some interesting results which are given below.

To 200 c.c. of fresh separated milk contained in a flat dish about 1 inch deep, 10 c.c. N/10 lactic acid and 2 c.c. commercial rennet are added, the dish being kept for one hour in a water bath at 45° C. The block of curd so obtained is turned out, and cut into 3/4 inch cubes with a sharp knife. These cubes of curd are then immersed in small beakers containing acid and salt solutions of varying concentration as already explained in the case of gluten. Experimenting in this way, it is found that the curd remains coherent in water, and in very dilute acids, but begins to disintegrate in hydrochloric acid at N/300, and in lactic acid at about N/50. In the case of hydrochloric acid the rate of disintegration increases with the concentration up to about N/55, when it attains a maximum. Further increase in the concentration slows the rate of disintegration, until the curd remains coherent again at a concentration of about N/10. In the case of lactic acid, the rate of disintegration increases continuously with the concentration,

and no practicable concentration could be found which would again produce coherence.

This behaviour of hydrochloric and lactic acids on casein is exactly similar to their behaviour with gluten, and this similarity is made all the more striking when the action of salts in conjunction with these acids is investigated. Mr Richardson has roughly measured the concentration of salt required to produce coherence with varying concentrations of hydrochloric and lactic acids, his critical point being that concentration which made the curd cohere just enough to enable it to be picked out of the beaker with a glass rod.

He finds with hydrochloric acid that as the concentration is raised from N/300 to N/50, the concentration of sodium chloride required to preserve the coherence of the curd increases from the merest trace to N/10. For concentrations of HCl between N/50 and N/30, the concentration of NaCl remains constant at about N/10. As the concentration of HCl rises from N/30 to N/10, the concentration of NaCl falls from N/10 to zero. These results when plotted make a curve almost exactly like that for gluten in NaCl and HCl in Pl. VI. Fig. 1. For lactic acid, increasing concentrations of acid require increasing additions of salt to preserve coherence, and the curve obtained by plotting the results is of exactly the same kind as that for gluten in lactic acid and NaCl in Pl. VI. Fig. 5. Furthermore, the water content of the curd, as determined by drying to constant weight blocks drained for half-an-hour on tightly stretched muslin, varies in much the same way as the water content of glutens. Thus in one set of experiments, curd in equilibrium with a solution whose concentration of acid and salt came just inside the curve contained 93 per cent. of water. By increasing the salt until the point came just outside the curve, the water content fell to 91 per cent.

In another experiment, using hydrochloric acid and no salt, curd in equilibrium with N/1000 HCl contained 81 per cent. of water, as compared with 91 per cent. when in equilibrium with N/10 HCl, and 78 per cent. in N/2 HCl.

These experiments show that the consistency and water content of curd depends on the concentration of the acid and salt solution with which it is in contact.

Before concluding, I take this opportunity of once more expressing my thanks to Mr A. E. Humphries for supplying me with numberless samples of flour of known baking properties, to Mr G. G. Chapman,

B.A., of Peterhouse, and to Mr A. G. Simpson, B.A., of Trinity College, who have made many analyses and gluten tests for me, and to Mr W. B. Hardy, M.A., F.R.S., who has helped me all through the work with advice and suggestions.

Summary.

It is shown that the properties of gluten depend on the nature and concentration of acid and salts in the solution with which it is in contact, and that the connexion between the properties of gluten and the concentration of acid and salts is a peculiar one which would not be made evident by comparison of analytical figures with bakers' marks. This connexion is shown by curves in Pl. VI. Figs. 1—5.

The properties of gluten which vary with concentration of acid and salt are coherence, elasticity, and water content, and it is suggested that these properties have an important bearing on the shape of the loaf, and that a knowledge of the acidity and soluble salt content of a flour gives a clue to the factor of strength which decides whether the flour will make a good shaped loaf.

Finally it is suggested that the method of investigation adopted may be expected to throw light on all problems depending on the manipulation of proteids, cheese making being especially mentioned.

NOTE ON IMMUNE WHEATS.

By ALBERT HOWARD, M.A., F.L.S., *Imperial Economic Botanist to the Government of India*, AND GABRIELLE L. C. HOWARD, M.A., *formerly Fellow of Newnham College, Cambridge.*

WHILE reading the two interesting papers[1] on immune wheats in the last number of this *Journal* it occurred to us that our observations on rust resistant wheats in India might be of some interest. During the past two years a large number of varieties of Indian and European wheats have been grown by us at Pusa in Behar and at Lyallpur in the Punjab, one of the objects being to obtain wheats immune or at least resistant to rusts which would serve as parents in raising rust resistant hybrids. Biffen last year suggested that a trial should be made with Einkorn (*Triticum monococcum vulgare*, Kcke.), and kindly supplied us with a sample of the seed. Another sample was obtained from Messrs Vilmorin, and the sowings were made at the ordinary time, in October 1906 at Pusa and in November of the same year at Lyallpur. In all cases the grains germinated and produced the characteristic thick grass-like tufts of foliage but in no instance were ears formed, the plants remaining in the vegetative condition up to harvest time (March 1907 at Pusa and May 1907 at Lyallpur). Consequently no use could be made of Einkorn as a parent.

The behaviour of this variety towards rust proved however to be of interest. At Lyallpur, the leaves remained uniformly green till the hot weather set in towards the end of April, when it was found that numerous light-green translucent spots were being formed in the leaves. These were no doubt produced by the entry of infecting tubes of rust spores through the stomata into the intercellular spaces of the leaves resulting in the breaking down of the host cells in the manner described by Miss Marryat in the paper referred to above. Only in one case was a pustule observed and the development of this was extremely feeble.

[1] Biffen, *Journal of Agricultural Science*, Vol. II. p. 109; Marryat, *ibid.* Vol. II. p. 129.

Nothing further was noted up to the first week in May when the hot winds began to wither up the plants. As regards immunity to rust the behaviour of Einkorn in the Punjab closely corresponds with that observed at Cambridge and elsewhere. There was no lack of infecting material as the wheats in the surrounding plots and also in the vast stretches of country for miles round in the Chenab Colony were affected by both *Puccinia glumarum*, Eriks. and Henn., and to a less extent by *Puccinia graminis*, Pers. The weather towards the end of the wheat-growing season was very wet and cloudy and distinctly favourable to rust attack.

At Pusa the results were quite different. Up to the harvest time no pustules were formed on the leaves and the plot was immune to all three rusts *Puccinia triticina*, *P. glumarum*, and *P. graminis*, which were abundant on some or other of the numerous varieties grown close by. The light-green translucent spots on the leaves mentioned above were however produced, and it was decided to allow the plot to remain after harvest time to see if any ears would be formed. Early in May it was found that vigorous uredospore pustules were produced in large numbers on the leaves and this continued through the month and into June, when the pustules began to darken through the copious formation of teleutospores. Examination of the pustules and spores showed that they belonged to the black rust of wheat (*Puccinia graminis*). Uredospores were noticed up to June 15th when the plot had to be transplanted. April and May are the hottest months of the year in the Indo-Gangetic plain, and at Pusa this year the maximum shade temperature in these months varied from 84·2° F. to 105° F. We have here an interesting result of the struggle between the host and the parasite in the case of a plant ordinarily immune to a fungus. Perfect immunity was enjoyed by the host till the hot weather of April and May lowered its vitality to such an extent that pustules were formed in large numbers just as in the case of a wheat susceptible to rust attack. The formation of uredospores during the hot season is also of interest in connexion with the way in which wheat rusts pass over from one wheat crop to another in India. At present we are quite in the dark as to the way in which the wheat rusts survive the hot weather and monsoon in India and infect the crop in the following cold season. The behaviour of Einkorn towards *Puccinia graminis* at Pusa during the present hot weather indicates the possibility that if a suitable host plant were available this fungus might pass from one wheat crop to another in the uredo stage

Although Einkorn did not prove of service as a rust resistant parent we were more fortunate with several varieties of Emmer[1] (*Triticum dicoccum*, Schrk.) which proved to be immune to the rusts met with at Lyallpur. These varieties flowered at the same time as the majority of the Indian wheats and reciprocal crosses were successfully made with several local wheats valuable in most respects but susceptible to rust attacks. The behaviour of Emmer towards rusts at Lyallpur closely followed that described by Miss Marryat in the case of Einkorn at Cambridge. Small circular sharply defined translucent spots and brownish-red dead areas surrounded by healthy green tissue were abundant on the leaves, but pustules were only very rarely produced and when found were very feebly developed. Side by side the wheats of the country were suffering from an epidemic of yellow rust (*Puccinia glumarum*). We hope that Emmer may be almost as useful in wheat breeding in certain parts of India as Einkorn has proved itself to be in Biffen's hands at Cambridge.

[1] The Indian varieties of Emmer are often referred to as Spelt wheats. We have however not yet discovered any Spelt wheats in India. As Spelts are mostly winter wheats it is hardly likely that they occur in India where the growing period of the crop is so short.

MENDELIAN HEREDITY IN COTTON.

By F. FLETCHER, B.A.

Indian Department of Agriculture.

IN Volume II. Part 2 of this *Journal* there appeared a note by W. L. Balls on the above subject, in which he states that "long lint is completely dominant over short." This dominance, the present writer in India has found to occur in the case of crosses between many very different varieties. The question is not however so simple as it would appear to be from Mr Ball's statement "that the breeding of pure types suitable to the needs of the manufacturer and the cultivator will possibly prove a little difficult"; for though length of staple is on the whole dominant we often get seeds that carry both long and short cotton. This is the case in some of the long-established American varieties, for instance "Bragg Long Staple" produces cotton of which almost the whole has a length of about $1\frac{3}{8}$ inches, but some of the seeds carry cotton both of this length and also of over twice the length, the latter inherited from its Sea-Island parent.

"Mixed staple" of this character I have repeatedly met with in breeding experiments, and its occurrence has terminated the career of more than one otherwise very promising hybrid.

With regard to the inheritance of the colour of the flower, this is in certain cases complex as Mr Balls states. Thus if a red-flowered variety be crossed with a yellow-flowered one, red- and yellow-flowered plants appear in about equal numbers in the F_1 generation. In the F_2 generation, I got of the red-flowered hybrid 428 giving rise to red-flowered plants and 114 to yellow, while of the yellow F_1 generation 12 only gave red to 474 yellow.

The above statement applies also to cases in which the red (or purple) colour is not diffused over the whole of the petal, but is confined to its base. Thus American (Upland) crossed with Sea-Island gave in the F_1 generation 11 plants without a purple "eye,"

16 with a faint one, and 8 with one as deep as the present Sea-Island.

In crossing yellow- and white-flowered varieties, however, we get complete dominance of the yellow.

Again some varieties have a short "fuzz" which completely covers the seeds after the removal of the cotton, while in others the seed is naked. The presence of fuzz appears to be completely dominant.

Some varieties differ from others only in that the cotton comes away from the seed much more easily. This looseness of the cotton on the seed also appears to be dominant.

The pairs of characters so far investigated are:

	Dominant	Recessive
Cotton	Fineness	Coarseness
	Length	Shortness
	Colour	Whiteness
Petal	Yellow colour	White
Seed	Fuzziness	Nakedness
	Loose cotton	Adhering cotton.
Plant	Lateness	Earliness

Unfortunately earliness appears to be coupled[1] with shortness of fibre, and it is doubtful how far earliness can be secured except at the expense of quality.

In the character of the leaves, shape of the bolls and habit of the plant, all shades intermediate between the parents are found in the F_1 generation.

I agree with Mr Balls in his opinion as to the evils resulting from the presence of "weeds" in the Egyptian cotton fields—one of which is the *G. Figarei* of Todaro, once grown as a field crop in Egypt under the name "Hamuli." In attempts to improve Egyptian cotton, it is necessary first to exclude the influence of this variety.

[1] Another case of coupling is that between the colour of the cotton and its weakness.

THE BOTANICAL AND CHEMICAL COMPOSITION OF THE HERBAGE OF PASTURES AND MEADOWS.

By S. F. ARMSTRONG, Univ. Dipl. Agric.,
Cambridge University Department of Agriculture.

INTRODUCTORY NOTE[1].

In view of the great importance of grazing in Great Britain, and especially in view of the increasing areas which have been laid down to grass during the last thirty years, it is remarkable that so little attention has been given to the composition of the herbage of pastures. Analyses of the mixed herbage produced in hay fields have frequently been made, but these give little information on the point at issue, for it is obvious that under the very different conditions existing in pasture and meadow, the balance of advantage in the struggle for sunlight and soil will probably rest with entirely different species in the two cases.

The most valuable information on the subject is that given by the work of the late Dr W. Fream[2], whose method of investigation was as follows: turfs two feet long, one foot wide, and nine inches deep were collected from 80 localities in the British Isles, and planted in the botanic garden of the College of Agriculture, Downton.

The herbage of these turfs was allowed to grow until ready to harvest, when it was clipped off with shears, and its composition ascertained by botanical separation. His figures thus show the composition of hay made from pastures and harvested in July, but they cannot be relied on to give anything like an accurate indication of the actual composition of the herbage available for stock grazing.

In order accurately to ascertain the composition of the herbage of a pasture at any particular season, it would be necessary to remove all edible herbage, and to separate and weigh the different species. This method however is so tedious as to be impracticable for a general survey, and it occurred to me that by measuring the relative proportions of ground surface occupied by the different species on a number of

[1] By T. H. Middleton, M.A.

[2] *J. R. A. S. E.* 2nd Series, xxiv. 415; 3rd Series, i. 359.

TABLE I. *The Herbage of Old Pastures. Names and description of Fields examined, arranged as far as possible according to quality and feeding value of their herbage.*

Ref. No.	Name of Field	Locality	County	Geological Formation	Soil	Situation and Aspect	Remarks
1	"The Seeds"	Slawston	Leicester	Upper Lias & Marlstone	Loam	High-lying and on S.W. slope exposed	Close to village, and has been well treated
2	Spence's Meadow	Do.	Do.	Marlstone	Clayey loam, deep, moist	Sheltered and level	Do., grazed and mown alternately
3	"Cow Close"	Do.	Do.	Lias	Moist, clayey loam	Do.	Very little cake fed on it
4	"Hall Close"	Welham	Do.	Do. and Alluvium	Deep and moist loam	Low-lying, flat	Lies against the river Welland
5	"The Old Churchyard"	Medbourne	Do.	Lias	Loam	High-lying on exposed southern slope	
6	"Round Pond" Field	Oxendon	Northants	Do.	Do.	Level	Have been laid down to grass about 30 years
7	Watson's "Seeds"	Little Bowden	Do.	Boulder clay	Clay	Situated on top of a hill	
8	"Church Field"	Oxendon	Do.	Do.	Heavy clay	North-east slope	No seeds mixture sown
9	"High Field"	Market Harboro'	Leicester	Lias	Loam	Gentle southern slope	
10	"The Grove"	Impington	Cambs.	Gault	Do.	Level, sheltered	
11	"Top Meadow"	Slawston	Leicester	Lias	Do.	Level	Grazed and mown alternately
12	"The Big Field"	Oxendon	Northants	Do.	Do.	High-lying, exposed southern slope	Old pasture with very close turf
13	"Washpit"	Ashley	Do.	Do.	Do.	Mostly low-lying	Two different types of soil and herbage
14	Unwin's "Old Pasture"	Impington	Cambs.	Gault	Dark loam	Level, sheltered	Very old pasture
15	"Solstaceway"	Slawston	Leicester	Lias	Loam	Level, open	Will not fatten bullocks
16	"Lane's End"	Thorpe Langton	Do.	Do.	Do.	Do.	Do.
17	"Middle Welham"	Welham	Do.	Do.	Do.	Level, sheltered	Grazed and mown alternately
18	"Clock Close"	Slawston	Do.	Do.	Do.	Low-lying and level	Soil suffers through excess of wetness; also badly treated
19	"Road Part"	Do.	Do.	Do.	Do.	Level	Soil thin, dry, and impoverished; grazed by sheep
20	Experimental Field, Plot 6	Cransley	Northants	Boulder clay	Clay	High-lying, but sheltered	A wretched pasture

Sampling of Soil and Herbage.

The soils were sampled by taking cores with a sampling tool from different places over a representative area. The analyses were made in duplicate. Herbage for chemical analysis was obtained by going over the same area and plucking off the mixed pasture plants with the thumb and forefinger. In this way about the same proportion of each plant was obtained as would be taken off by an ox in grazing. Duplicate samples were taken, wrapped in water-proof paper, labelled, and at once sent to the laboratory. The dry matter, nitrogen, and phosphate were determined in each sample, duplicate analyses being made. The duplicate samples taken as described were found to agree very satisfactorily in chemical composition.

Botanical Analysis of the Herbage.

As already stated in the introduction the botanical analyses of the herbage were made by estimating the proportion of ground surface occupied by each species. For this purpose a square frame was used which enclosed an area of one square foot. This space was further divided into square inches by means of cord tightly stretched across. After fastening the frame to the ground the number of square inches of bare surface, if any, were first counted. Then the larger and more conspicuous plants such as ryegrass, white clover, cocksfoot or weeds were similarly dealt with, and lastly the less abundant species. With constant practice and care the "total area" thus obtained did not differ from the actual area, 144 square inches, by more than three or four square inches which were added or subtracted proportionally. Frequently more than 80 per cent. of the surface was occupied by three or four species only.

A general idea of the herbage was first obtained and then a number of representative portions of the turf, usually from six to ten according to the character of the herbage, were examined in this way. The average of these was taken to represent the approximate composition of the herbage at the time.

Results obtained in this way were compared with the percentages found by separating and weighing the approximate constituents of the herbage of several fields. The figures (Table III) indicate a close agreement between the results obtained by either method. That the method employed gives the composition of the pasturage far more accurately than that of finding the composition by weight of a hay crop is clearly shown by a comparison of the results given in Tables II and III

TABLE II. *Showing, for example, in the case of three common pasture plants, how very different the percentages of each in the pasture, and in the hay crop may be.*

Place and Description	Abbotsley, 1905, New Pasture. Av. of eleven plots. Percentage in Pasture	Hay crop	Cransley, 1906, Old Pasture. Av. of five plots. Percentage in Pasture	Hay crop	Top Meadow, 1906, Very old grass land. Percentage in Pasture	Hay crop
Date	July	July	June	July	May	August
Trifolium repens	8·6	3·2	20·7	5·6	19·3	7·3
Lolium perenne	27·8 *	33·5 *	7·9	11·2	25·7	43·1
Cynosurus cristatus...	10·1 †	8·9 †	20·4	14·2	10·0	13·0

* Average of eight plots. These species were not sown on all the plots.
† „ four plots. „ „ „ „

TABLE III. *Comparison of the results of estimating the composition of herbage, (1) by weight, and (2) by the area occupied by each species.*

Figures give percentages.

Approximate constituents of herbage	* "The Grove" Area	Wt.	† "The Seeds" Area	Wt.	"Hall Close" Area	Wt.	"Old Church-yard" Area	Wt.	"Round Pond Field" Area	Wt.	‡ New Pasture, No. 19, Univ. Farm Area	Wt.
Total Grasses	56·6	59·8	56·3	56·3	61·4	61·3	55·1	57·7	50	49·5	46·9	42·8
White Clover.	32·0	30·0	42·1	42·5	36·3	36·0	43·9	42·3	50	50·5	46·3	56·3§
Yarrow.........	6·0	5·7	—	—	2·0	2·6	—	—	—	—	—	—
Miscellaneous	5·4	4·5	1·3	1·2	Tr	—	—	—	—	—	1·3	·9
Bare surface	—	—	·3	—	—	—	1·0	—	—	—	5·5	—
	100	100	100	100	99·7	99·9	100	100	100	100	100	100

* Average of four places. † Average of two places.
‡ Average of three places. The other fields one place each.
§ The rather large difference here is due to the removal of portions of clover runners which were thus included in the weight. On this type of pasture the proportion of creeping stems to foliage in the case of white clover was greater than on older turfs. They cannot be strictly regarded as edible herbage.

TABLE IV. *Rainfall recorded in the Market Harborough district.*

Monthly Rainfall.

October, 1905—September, 1906.

1905	Inches	*1906*	Inches
October	1·19	April	0·78
November ...	2·48	May	4·81
December ...	0·94	June	2·62
1906			
January......	3·66	July	1·69
February	2·22	August	1·26
March	1·46	September...	0·96
Winter rainfall	*11·95*	*Summer rainfall*	*9·12*
Average ,,	12·35	Average ,,	13·37
Diff. from Av.	−0·40	Diff. from Av.	−4·25

Weekly Rainfall.

Rainfall for each week from January 1st to July 28th, 1906. Also greatest rainfall recorded on any one day during the weekly period.

Successive weeks from January 1st	1906 Fall, Inches	1906 Max.	1906 Date	Successive weeks from April 16th	1906 Fall, Inches	1906 Max.	1906 Date
1	1·19	·62	January 6	16	0·18	·13	April 22
2	1·12	·48	,, 8	17	0·45	·25	,, 23
3	1·12	·33	,, 16	18	0·74	·22	May 2 and 3
4	0·23	·23	,, 24	19	0·22	·19	,, 7
5	0·27	·27	February 2	20	0·36	·18	,, 16 ,, 20
6	0·66	·66	,, 10	21	0·49	·29	,, 26
7	0·63	·24	,, 16	22	0·42	·30	June 1
8	0·17	·13	,, 19	23	0·00	—	—
9	0·71	·33	,, 27	24	0·56	·34	,, 15
10	0·48	·24	March 10	25	0·00	—	—
11	0·32	·28	,, 14	26	1·64 *	·82	,, 28 ,, 29
12	0·29	·19	,, 24	27	0·00	—	—
13	0·15	·15	,, 26	28	0·25	·10	July 10
14	0·15	·15	April 2	29	0·00	—	—
15	0·00	—	—	30	1·39	1·16	,, 27

* Measured in two successive days.

DESCRIPTION OF SEASON.

Table IV gives the rainfall recorded in the neighbourhood of Market Harborough during the time this work was in progress. The autumn of 1905 was cold with less than the average fall of rain. The season of 1906 was remarkable for the amount of bright sunshine recorded, but the mean temperature was not above the average. The total fall of rain for the twelve months—October 1905 to September 1906—was much below the average, and the deficiency occurred chiefly during the summer. It should be noticed that although 4·26 inches of rainfall was measured in June and July, of this amount 2·80 inches fell during three days. The dry weather during the latter part of June and throughout July was especially trying for the pastures.

DISCUSSION OF RESULTS.

BOTANICAL COMPOSITION OF HERBAGE[1].

a. *First-rate Old Pastures.*

The first three fields in Table V represent the richest type of old grazing land found in the Market Harborough district. In No. 1 annual meadow grass (*Poa annua*) was present in quite an unusual quantity, but otherwise the composition of the herbage on the three fields was very similar.

An average of these fields gives the following order of relative abundance of the more common species:

1. White Clover (*Trifolium repens*).
2. Ryegrass (*Lolium perenne*).
3. Crested Dogstail (*Cynosurus cristatus*).
4. Fiorin (*Agrostis alba* var. *stolonifera*).
5. Rough-stalked Meadow Grass (*Poa trivialis*).
6. Yorkshire Fog (*Holcus lanatus*).

The most striking figures in this table are the very high percentages of white clover and ryegrass which together formed more than two-thirds of the entire herbage. Fiorin was rather abundant, and also Yorkshire fog on No. 4. The low percentage of weeds consisted chiefly of the bulbous buttercup (*Ranunculus bulbosus*).

[1] N.B. The analyses quoted in comparing each type of herbage are always the average of the two examinations made during the summer of 1906 which are conveniently grouped in Table X. In Tables V—XI the figures give the percentage of the surface occupied by each species.

TABLE V. *Botanical Composition of the Herbage of four first-rate Old Pastures.*

Reference No.	1				8				4			
Name	"The Seeds"				"Cow Close," Section A.				"Hall Close," Section A.			
Date of Examination	Oct. 1905	May 24th, 1906	July 20th, 1906	*Average*	Oct. 1905	May 24th, 1906	Aug. 4th, 1906	*Average*	Oct. 1905	May 12th, 1906	Aug. 4th, 1906	*Average*
No. of places examined	4	8	10	*7*	6	8	10	*8*	8	6	8	*7*
Lolium perenne	36·4	35·0	37·5	*36·3*	43·3	28·1	33·4	*35·1*	38·9	24·2	37·0	*33·4*
Dactylis glomerata	·7	—	—	*·2*	·3	·8	—	*·4*	—	1·7	1·0	*·9*
Cynosurus cristatus	7·4	4·3	2·7	*4·8*	12·1	13·3	8·5	*11·3*	6·6	7·1	1·7	*5·1*
Alopecurus pratensis	·9	1·1	—	*·7*	·6	1·0	—	*·5*	—	—	—	—
Phleum pratense	4·0	1·7	—	*1·9*	·7	1·5	trace	*·7*	1·9	3·4	2·0	*2·4*
Avena flavescens	—	—	—	—	—	—	—	—	·6	—	—	*·2*
Poa trivialis	1·4	4·0	1·8	*2·4*	·8	4·4	1·5	*2·2*	5·5	4·9	1·8	*3·9*
Poa annua	8·2	11·8	12·8	*10·9*	—	—	trace	*trace*	2·1	1·8	trace	*1·3*
Festuca ovina et vars.	—	—	—	—	·5	trace	—	*·2*	·5	1·2	·7	*·8*
Agrostis alba, var. stolonifera	12·8	4·0	4·3	*7·0*	5·4	4·5	4·5	*4·8*	11·2	7·6	11·8	*10·0*
Holcus lanatus	1·0	1·2	1·2	*1·1*	2·8	2·4	2·0	*2·2*	17·2	5·0	6·5	*9·6*
Hordeum pratense	—	—	—	—	—	—	—	—	—	—	—	—
Aira cæspitosa	—	—	—	—	—	—	—	—	1·1	—	—	*·4*
Trifolium pratense	—	—	—	—	1·3	—	trace	*·4*	—	—	—	—
Trifolium repens	24·6	35·5	38·9	*33·0*	26·2	39·7	47·5	*37·8*	12·8	40·3	36·6	*29·7*
Ranunculus sps.	·9	1·4	—	*·8*	2·2	3·2	trace	*1·8*	1·2	2·5	1·1	*1·6*
Bellis perennis	—	—	—	—	—	—	—	—	·3	—	—	*·1*
Taraxacum officinale	·9	—	—	*·3*	—	—	—	—	·6	—	—	*·2*
Mosses	—	trace	—	*trace*	2·6	1·0	trace	*1·2*	—	—	—	—
Various weeds	·7	trace	·4	*·4*	·4	trace	trace	*·2*	—	trace	trace	*trace*
Totals	99·9	100·0	99·6	*99·8*	99·2	99·9	97·4	*98·8*	100·0	99·7	99·2	*99·6*
Gramineae	72·8	63·1	60·3	*65·3*	66·5	56·0	49·9	*57·4*	85·6	56·9	61·5	*68·0*
Leguminosae	24·6	35·5	38·9	*33·1*	27·5	39·7	47·5	*38·2*	12·8	40·3	36·6	*29·7*
Weeds	2·5	1·4	·4	*1·4*	5·2	4·2	trace	*3·2*	2·1	2·5	1·1	*1·9*

Reference No.	14				
Name	"Unwin's Pasture"				
Date of Examination	Sept. 1905	March 7th, 1906	April 27th, 1906	[illegible]	[illegible]
No. of places examined	4	4	5	[illegible]	[illegible]
Lolium perenne	47·5	52·0	[illegible]	[illegible]	[illegible]
Dactylis glomerata	3·4	4·1	[illegible]	[illegible]	[illegible]
Cynosurus cristatus	trace	·6	[illegible]	[illegible]	[illegible]
Alopecurus pratensis	—	—	1·1	—	[illegible]
Phleum pratense	trace	—	—	[illegible]	[illegible]
Avena flavescens	—	·6	[illegible]	[illegible]	[illegible]
Poa trivialis	4·9	[illegible]	[illegible]	[illegible]	[illegible]
Poa annua	—	—	—	[illegible]	[illegible]
Festuca ovina et vars.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Agrostis alba, var. stolonifera	—	[illegible]	[illegible]	[illegible]	[illegible]
Holcus lanatus	—	—	—	[illegible]	[illegible]
Hordeum pratense	[illegible]	—	—	[illegible]	[illegible]
Aira cæspitosa	—	—	—	[illegible]	[illegible]
Trifolium pratense	—	—	—	[illegible]	[illegible]
Trifolium repens	12·0	[illegible]	[illegible]	[illegible]	[illegible]
Ranunculus sps.	4·1	[illegible]	[illegible]	[illegible]	[illegible]
Bellis perennis	[illegible]	10·5	[illegible]	[illegible]	[illegible]
Taraxacum officinale	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mosses	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Various weeds	—	—	[illegible]	[illegible]	[illegible]
Totals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Gramineae	71·7	67·7	[illegible]	[illegible]	[illegible]
Leguminosae	12·0	6·2	13·5	13·8	[illegible]
Weeds	15·8	24·8	26·9	14·2	*19·0*

NOTE. "Unwin's Pasture"—a small enclosure near buildings—is placed here as representing pasture of good quality *for the neighbourhood* of Cambridge. It is however much inferior to fields Nos. 1, 8 and 4.

TABLE VI.

Botanical Composition of the Herbage of four Excellent Recent Pastures.

Reference No.	5		7		6		8	
Name	"The Old Churchyard"		"Watson's Seeds"		"Round Pond Field"		* "Church Field"	
Date of Examination, 1906	June 8th	July 31st	June 8th	July 24th	June 5th	July 26th	June 5th	July 26th
No. of places examined ...	8	10	8	10	10	10	8	10
Lolium perenne	31	32·5	28	47·2	32·1	35·7	30·7	41·3
Dactylis glomerata	4	4·8	12	7·0	2·3	1·5	1·1	1·0
Cynosurus cristatus	10	6·0	11	2·8	14·6	10·0	10·1	9·4
Alopecurus pratensis	—	—	trace	—	—	trace	trace	trace
Phleum pratense...........	2	trace	trace	—	1·8	trace	3·7	trace
Avena flavescens...........	trace	trace	1	·7	—	trace	·7	—
Poa trivialis.................	6	6·6	11	3·5	11·8	1·7	12·8	2·9
Poa pratensis	1	trace	trace	trace	—	—	·6	—
Poa annua	4	5·0	2	2·8	2·2	3·5	·7	1·6
Festuca pratensis	1	1·0	—	—	—	—	—	—
Festuca ovina	—	trace	1	·5	·4	trace	1·8	trace
Agrostis alba, var. stolonifera	trace	trace	trace	trace	2·5	5·2	1·8	4·5
Holcus lanatus	1	trace	5	1·2	2·8	2·0	6·6	2·2
Agropyrum repens	trace	—	—	trace	trace	—	trace	—
Trifolium repens............	37	40·8	21	27·8	29·5	38·6	26·5	35·1
Trifolium pratense.........	—	—	trace	trace	—	—	—	—
Ranunculus sps.............	—	—	†	†	trace	trace	·5	·5
Taraxacum officinale	—	—	†	†	—	—	—	—
Bellis perennis	—	—	†	†	trace	—	·7	·8
Plantago lanceolata	—	—	†	†	—	—	—	—
Carduus sps.	—	—	†	†	—	—	—	—
Mosses........................	—	—	†	†	trace	—	·7	—
Various weeds..............	—	—	—	—	trace	trace	·4	—
Bare surface................	—	·5	—	·7	—	·6	—	—
Totals	98·0	96·7	99·5	98·4	100·0	98·8	99·4	99·3
Gramineae	60·0	55·9	71·0	65·2	70·5	59·6	70·6	62·9
Leguminosae	37·0	40·3	21·0	27·8	29·5	38·6	26·5	35·1
Weeds	1·0	trace	7·5	4·7	trace	trace	2·3	1·3

* "Church Field," Oxendon, was not sown down, but went to grass naturally.

† Denotes that the quantity of the species present was not ascertained separately, but is included in the totals at the base of the table.

"Unwin's Pasture" (No. 14), selected as being one of the best near Cambridge, is of quite a different type from the foregoing. It has an old and very thick turf growing on a dark loam. The figures show that weeds—especially daisies (*Bellis perennis*)—were abundant, and that sheep's fescue (*Festuca ovina*) was a conspicuous grass. Even here, however, ryegrass and white clover occupied about one-half of the surface.

Excellent Recent Pastures.

It was ascertained that some of the finest grazing land in the Market Harborough district had been formed about thirty years ago. Table VI gives the composition of the herbage of four of these recent pastures, which were considered to be equal to the best old grazing land. Taking an average of these fields, it is seen that ryegrass and white clover again formed about two-thirds of the herbage. Compared with the best old pasture fiorin was less common, while crested dogstail, cocksfoot (*Dactylis glomerata*) and rough-stalked meadow grass were rather more abundant. Nos. 5, 6 and 8 were remarkably free from weeds.

c. Second-rate Old Pastures.

Pasture of good feeding quality, but not considered first-class for the district, is represented by the fields in Table VII. Compared with the best old pastures (see Table X) the chief botanical difference in the herbage was the diminished quantity of white clover present. On the whole ryegrass, crested dogstail, and weeds were rather more abundant, but the slight falling off in quality appeared to be due rather to the condition of the soil than to the species composing the herbage.

d. Inferior Old Pastures.

Fields Nos. 15, 16 and 19 (Table VIII) represent the inferior grazing land of the neighbourhood. The herbage of these pastures presents a remarkable contrast to the fields in Tables V and VI. Looking at the averages of "Road Part" and "Solstaceway," it will be seen that in both cases fiorin (chiefly *Agrostis vulgaris*) and weeds occupied between 40 and 50 per cent. of the surface. Ryegrass and white clover took quite secondary places. The former occupied on the average only one-half and the latter only one-fifth of the proportion of surface which they filled in the best old pastures.

TABLE VII. *Botanical Composition of the Herbage of three Old Pastures*—which were considered to be of very good feeding quality, though not first-rate.

Reference No.	9			12			13		
Name	"Highfield"			"The Big Field"			"Washpit" (Section C)		
Date of Examination, 1906	May 31st	July 24th	*Average*	June 6th	July 30th	*Average*	June 7th	July 28th	*Average*
No. of places examined ...	8	10	*9*	6	10	*8*	6	6	*6*
Lolium perenne	38·8	53·4	*46·1*	30·2	36·0	*33·1*	19·3	36·2	*27·6*
Dactylis glomerata	2·3	1·7	*2·0*	—	—	—	3·2	1·6	*2·4*
Cynosurus cristatus	6·7	3·5	*5·1*	17·4	13·5	*15·5*	13·3	3·7	*8·5*
Alopecurus pratensis	—	trace	*trace*	—	trace	*trace*	—	trace	—
Phleum pratense............	4·2	1·0	*2·6*	2·0	·7	*1·3*	1·9	1·4	*1·6*
Avena flavescens............	2·7	trace	*1·4*	—	—	—	4·5	2·2	*3·3*
Poa trivialis..................	10·7	·9	*5·8*	5·1	·7	*2·9*	2·9	1·0	*1·9*
Poa annua	·7	—	*·3*	1·7	2·8	*2·2*	—	—	—
Anthoxanthum odoratum	—	—	—	3·4	2·5	*3·0*	—	—	—
Festuca ovina	·7	1·0	*·9*	trace	—	*trace*	7·8	7·2	*7·5*
Agrostis alba, var. stolonifera	7·3	5·7	*6·5*	4·0	5·3	*4·6*	1·7	6·6	*4·1*
Holcus lanatus..............	trace	1·4	*·7*	11·0	6·9	*9·0*	2·8	2·3	*2·6*
Trifolium repens............	20·4	27·5	*24·0*	21·4	30·9	*26·0*	18·9	28·8	*23·8*
Achillea Millefolium	—	trace	*trace*	—	—	—	1·9	trace	*·9*
Ranunculus sps.	4·3	2·0	*3·1*	2·0	trace	*1·2*	5·5	trace	*2·8*
Taraxacum officinale	—	—	—	—	—	—	*	*	*
Bellis perennis	—	—	—	—	—	—	9·5	1·1	*5·3*
Plantago lanceolata	—	—	—	—	—	—	*	*	—
Mosses	—	—	—	1·0	trace	*·6*	*	trace	*trace*
Various weeds...............	1·1	—	*·5*	·7	trace	*trace*	6·8	5·3	*6·0*
Bare surface..................	—	1·0	*·5*	—	trace	*trace*	—	1·7	*·8*
Totals	99·9	99·1	*99·5*	99·9	99·3	*99·4*	100·0	99·1	*99·1*
Gramineae	74·1	68·6	*71·4*	74·8	68·4	*71·6*	57·4	62·2	*59·5*
Leguminosae	20·4	27·5	*24·0*	21·4	30·9	*26·0*	18·9	28·8	*23·8*
Other useful Plants.........	—	trace	*trace*	—	—	—	1·9	—	*·9*
Weeds	5·4	2·0	*3·6*	3·7	trace	*1·8*	21·8	6·4	*14·1*

NOTES. No. 9 was the field examined by Lawes and Gilbert on several occasions between 1879 and 1888. Its quality has somewhat deteriorated in recent years.

An asterisk shows that the quantity of the species was not ascertained separately, but that it has been included in the totals at the foot of the table.

Reference No.	19			15				16	20
Name of Field	"Road Park"			"[illegible]"				[illegible]	Plot 6, Cransley
Date of Examination, 1906	May 14th	Aug. 1st	*Average*	Oct. 1905	May 21st	Aug. 1st	*Average, May-Aug.*	Oct. 1905	June 25th, 1906
No. of places examined ...	6	8	7	6	4	4	4	6	6
Lolium perenne	12·4	15·7	*14·1*	39·4	18·0	18·0	*18·0*	44·6	1·0
Dactylis glomerata	9·9	9·1	*9·5*	5·9	1·6	trace	*·9*	3·0	3·4
Cynosurus cristatus	8·5	5·4	*7·0*	14·8	18·2	7·0	*12·6*	13·6	18·9
Alopecurus pratensis	—	—	—	·6	1·3	—	*·6*	—	—
Phleum pratense	—	—	—	1·0	1·3	—	*·6*	—	—
Avena flavescens	1·5	trace	*·8*	1·5	3·7	1·3	*2·5*	1·1	2·0
Poa trivialis	—	trace	*trace*	—	trace	—	*trace*	·7	—
Poa pratensis	—	—	—	—	—	—	—	—	trace
Anthoxanthum odoratum	·8	1·2	*1·0*	—	2·6	·8	*1·7*	—	—
Festuca ovina et vars.	3·2	3·7	*3·4*	1·3	2·0	2·7	*2·3*	1·4	5·8
Festuca pratensis	—	—	—	—	—	—	—	—	trace
Agrostis alba et vars.	17·4	19·5	*18·5*	14·8	22·7	51·8	*37·2*	13·5	trace
Holcus lanatus	1·0	1·2	*1·1*	6·0	1·3	1·4	*1·3*	·8	3·0
Agropyrum repens	1·3	—	*·6*	—	—	—	—	—	1·2
Trifolium minus	—	—	—	—	—	—	—	—	1·7
Trifolium repens	3·4	6·8	*5·1*	3·7	9·3	14·0	*11·6*	10·2	6·0
Trifolium pratense	—	1·7	*·8*	2·3	—	—	—	2·4	—
Lotus corniculatus	7·0	6·2	*6·6*	1·0	·7	trace	*·4*	—	—
Medicago lupulina	—	—	—	—	—	—	—	—	15·0
Achillea Millefolium	1·9	5·8	*3·8*	—	—	—	—	—	—
Ranunculus sps.	8·9	*	*	2·4	10·2	—	*5·1*	3·5	trace
Taraxacum officinale	·9	*	*	—	1·3	—	*·6*	1·1	—
Bellis perennis	3·6	*	*	·8	—	—	—	1·3	11·4
Plantago lanceolata	2·7	*	—	·4	—	1·0	*·5*	trace	6·2
Luzula campestris*	2·5	trace	—	—	1·7	—	*·8*	—	·6
Leontodon sps. / Hieracium sps. / Hypochœris sps.	7·3	13·4	*10·3*	—	2·5	2·0	*2·2*	—	10·2
Mosses	1·4	1·4	*1·4*	—	—	—	—	1·7	2·2
Carex glauca	—	—	—	—	—	—	—	—	7·6
Ajuga reptans	—	—	—	—	—	—	—	—	1·3
Various weeds	1·0	*	*	1·2	—	—	—	1·0	trace
Bare surface	1·3	1·3	*1·3*	·6	—	—	—	—	—
Totals	97·9	96·6	*97·2*	97·7	98·4	100·0	*98·9*	99·9	97·5
Gramineae	56·0	55·3	*56·0*	85·3	72·7	83·0	*77·7*	78·7	35·3
Leguminosae	10·4	14·7	*12·5*	7·0	10·0	14·0	*12·0*	12·6	22·7
Other useful Plants	1·9	5·8	*3·8*	—	—	—	—	—	—
Weeds	28·3	19·0	*23·6*	4·6	15·7	3·0	*9·2*	8·6	39·5

* See note, Table X.

Crested dogstail was more abundant than on the better fields. Birdsfoot trefoil (*Lotus corniculatus*), a plant typical of impoverished soils, was plentiful on "Road Part."

The herbage of "Lane's End" was very similar to that of "Solstaceway," and was only examined once.

Plot 8, Cransley, near Kettering, represents for comparison an extreme type of poor pasture. The large quantities of weeds, crested dogstail and medick (*Medicago lupulina*), and the extremely low percentages of ryegrass and white clover should be noted.

e. *Meadows.*

With each of the four meadows in Table IX the usual practice was to graze and mow in alternate years.

No. 2 represents the choicest meadow land of the neighbourhood. It is grazed by dairy cows and receives a dressing of dung every other season. The remarkably high percentage of white clover present, in spite of mowing, was no doubt largely due to the good treatment received, and also to the fact that the hay crop is always removed early in the season, thus allowing this plant to spread a good deal in the aftermath. Ryegrass with white clover formed 75 per cent. of the herbage.

No. 11 is a meadow of above the average quality. It has been grazed by sheep, but otherwise unmanured. Compared with No. 2 its herbage shows the following points of difference:—a much smaller percentage of white clover; a much larger quantity of fiorin, and increased quantities of Yorkshire fog, cocksfoot and crested dogstail.

Nos. 17 and 18 represent two types of poor meadow land of the neighbourhood. Both are unmanured.

No. 17 lies rather dry and is grazed by sheep. The figures show that 50 per cent. of its surface was occupied by fiorin (chiefly *Agrostis vulgaris*) and other weeds.

No. 18 was grazed by horses. It suffered from want of drainage and grew herbage of which nearly 60 per cent. was Yorkshire fog, fiorin and tufted hair grass (*Aira cæspitosa*), all typical of wet soils. On the two last fields ryegrass and white clover together formed less than one-fifth of the herbage.

In Table X each of the foregoing fields are grouped according to the type of pasture and the results averaged to facilitate comparison.

TABLE IX. *Botanical Composition of the Herbage of four Meadows near Slawston.*

Reference No.	2				11				17				18		
Name	"Spence's Meadow"				"Top Meadow"				"Middle Welham"				"Clock Close"		
Date of Examination	Oct. 1905	May 19th, 1906	*Aug. 7th, 1906	*Average*	Oct. 1905	May 18th, 1906	*Aug. 7th, 1906	*Average*	Oct. 1905	May 10th, 1906	*Aug. 4th, 1906	*Average*	May 16th, 1906	Aug. 4th, 1906	*Average*
No. of places examined ...	6	8	6	*7*	8	6	4	*6*	4	6	3	*4*	6	6	*6*
Lolium perenne	20·8	16·7	41·3	*26·3*	34·2	25·7	30·0	*30·0*	11·6	9·7	14·0	*11·8*	10·6	15·3	*13·0*
Dactylis glomerata	2·0	2·5	3·4	*2·6*	4·8	6·7	11·3	*7·6*	8·0	3·1	5·5	*5·5*	—	—	—
Cynosurus cristatus	10·8	2·0	2·8	*5·2*	9·3	10·0	7·0	*8·8*	7·0	7·5	3·4	*4·8*	18·0	9·0	*13·5*
Phleum pratense	—	—	—	—	—	—	—	—	2·3	trace	—	*·8*	—	—	—
Avena flavescens	2·2	3·1	2·4	*2·6*	·3	4·6	2·7	*2·5*	2·4	4·0	trace	*2·4*	—	—	—
Poa trivialis	4·9	4·0	trace	*2·7*	1·4	1·0	trace	*·8*	·9	1·7	trace	*·9*	5·1	—	*2·5*
Anthoxanthum odoratum	—	trace	trace	*trace*	—	·8	trace	*·3*	—	2·0	2·9	*1·6*	4·0	1·8	*2·9*
Festuca ovina	1·0	trace	2·0	*1·0*	1·0	·7	2·0	*1·2*	4·5	5·1	4·0	*4·5*	3·0	1·0	*2·0*
Agrostis alba et vars.	—	—	trace	*trace*	14·9	13·5	12·0	*13·5*	10·8	12·3	33·0	*18·7*	17·5	29·0	*23·3*
Holcus lanatus	6·0	trace	2·4	*2·8*	8·9	3·7	8·7	*7·1*	—	1·4	1·1	*·8*	17·0	15·6	*16·3*
Aira cæspitosa	—	—	—	—	—	—	trace	*trace*	—	—	—	—	17·5	16·7	*17·1*
Alopecurus pratensis	—	—	—	—	1·0	—	—	*·3*	·7	trace	—	*·3*	3·7	trace	*1·9*
Hordeum pratense	—	—	—	—	·9	—	—	*·3*	—	—	—	—	—	—	—
Trifolium pratense	1·6	1·9	4·9	*2·8*	—	—	—	—	1·0	—	—	*·8*	—	trace	*trace*
Trifolium repens	38·8	61·2	31·4	*43·8*	16·4	19·3	19·5	*18·4*	12·5	11·0	1·6	*8·4*	1·5	7·0	*4·3*
Lotus corniculatus	—	—	—	—	—	—	—	—	1·2	3·8	—	*1·7*	—	—	—
Achillea Millefolium	—	—	—	—	—	—	—	—	6·0	trace	trace	*2·1*	—	—	—
Ranunculus sps.	3·8	†	†	†	3·0	9·0	—	*4·0*					2·1	2·3	*2·2*
Bellis perennis	3·6	†	†	†	—	—	—	—					—	—	—
Taraxacum officinale	1·4	†	4·9	†	—	—	—	—					—	—	—
Plantago lanceolata	—	†	—	*trace*	—	—	—	—	30·0	36·9	25·7	*30·9*	—	—	—
Rumex Acetosa	—	—	—	—	—	2·3	—	*·8*					—	—	—
Mosses	2·7	—	1·2	*1·3*	—	1·0	trace	*·3*					—	—	—
Various weeds	—	—	—	—	·6	·7	—	*·4*					—	trace	*trace*
Bare surface	—	—	1·2	*·4*	—	·7	trace	*·2*	—	·8	trace	*·3*	—	2·2	*1·1*
Totals	99·6	99·4	98·8	*99·3*	96·7	99·7	98·2	*96·5*	98·9	99·3	91·2	*96·6*	100·0	99·4	*99·6*
Gramineae	47·7	28·3	54·3	*43·4*	76·7	66·7	73·7	*72·4*	48·2	46·8	63·9	*51·9*	96·4	87·9	*92·1*
Leguminosae	40·4	63·1	36·3	*46·6*	16·4	19·3	19·5	*18·4*	14·7	14·8	1·6	*10·4*	1·5	7·0	*4·2*
Other useful Plants	—	—	—	—	—	—	—	—	6·0	trace	trace	*2·0*	—	—	—
Weeds	11·5	8·0	7·0	*8·9*	3·6	13·0	trace	*5·5*	30·0	36·9	25·7	*30·9*	2·1	2·3	*2·2*

* Composition of aftermath.
† Indicates that the quantities of these species present were not determined separately, but have been included in the totals.

Examined twice during the summer of 1906. (1) May—June. (2) July—August.†

	Excellent Old Pastures				Excellent Recent Pastures					Good Old Pastures				Inferior Old Pastures			Meadows			
Reference No.	1	3	4		5	7	6	8		9	12	13		15	19		2	11	17	18
Name	"The Seeds"	"Cow Close"	"Hall Close"	*Average*	"The Old Churchyard"	"Watson's Seeds"	"Round Pond Field"	"Church Field"	*Average*	"High Field"	"The Big Field"	"Washpit" (Section O)	*Average*	"Solstaceway"	"Road Part"	*Average*	"Spence's Meadow"	"Top Meadow"	[illegible]	[illegible] Close"
No. of places examined ...	9	9	7	*8*	9	9	10	9	*9*	9	8	6	*8*	4	7	*5*	7	5	[illegible]	6
Lolium perenne	36·3	30·7	30·6	*32·5*	31·8	37·6	33·9	36·0	*34·8*	46·1	33·1	27·6	*35·6*	18·0	14·1	*16·0*	29·0	27·3	11·[illegible]	[illegible]
Dactylis glomerata	—	·4	1·4	*·6*	4·4	9·5	1·9	1·0	*4·2*	2·0	—	2·4	*1·4*	·9	9·5	*5·2*	2·8	3·0	4·5	—
Cynosurus cristatus	3·5	10·9	4·4	*6·3*	8·0	7·0	12·3	9·8	*9·3*	5·1	15·5	8·5	*9·7*	12·6	7·0	*9·8*	2·4	8·5	5·5	13·5
Alopecurus pratensis	·6	·5	—	*·4*	—	trace	trace	trace	*trace*	trace	trace	trace	*trace*	·6	—	—	—	—	trace	1·9
Phleum pratense............	·9	1·0	2·7	*1·5*	1·0	trace	1·2	2·0	*1·0*	2·6	1·3	1·6	*1·8*	·6	—	—	—	—	trace	—
Avena flavescens............	—	—	—	—	trace	·9	trace	·4	*·3*	1·4	—	3·3	*1·6*	2·5	·8	*1·7*	2·7	3·0	2·2	—
Poa trivialis.................	3·0	3·0	3·1	*3·0*	6·3	7·2	6·6	7·9	*7·0*	5·8	2·9	1·9	*2·8*	trace	trace	*trace*	2·2	·6	1·0	2·5
Poa pratensis	—	—	—	—	trace	trace	—	·3	*trace*	—	—	—	—	—	—	—	—	—	—	—
Poa annua	12·3	—	·9	—	4·4	2·1	2·8	1·2	*2·6*	·3	2·2	—	*·9*	—	—	—	—	—	—	—
Anthoxanthum odoratum	—	trace	—	—	—	—	—	—	—	—	3·0	—	—	1·7	1·0	*1·4*	trace	·5	2·5	2·6
Festuca pratensis...........	—	—	—	—	1·0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Festuca ovina et vars.	—	trace	1·0	—	—	·8	·4	1·0	*·6*	·9	trace	7·5	*2·8*	2·3	3·4	*2·9*	1·1	1·4	4·5	2·0
Agrostis alba et vars.......	4·2	4·5	9·5	*6·1*	trace	trace	3·7	3·2	*1·7*	6·5	4·6	4·1	*5·1*	37·2	18·5	*27·8*	trace	12·7	22·6	28·2
Holcus lanatus	1·2	2·2	5·7	*3·0*	·6	3·1	2·4	4·4	*2·6*	·7	9·0	2·6	*4·1*	1·3	1·1	*1·2*	1·3	6·2	1·3	16·3
Agropyrum repens	—	—	—	—	trace	trace	—	trace	*trace*	—	—	—	—	—	·6	—	—	—	trace	—
Aira cæspitosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17·1
Other grasses	—	—	—	—	—	trace	—	—	—	—	—	trace	—	—	—	—	—	trace	—	—
Trifolium pratense *.........	—	trace	—	—	—	—	—	—	—	—	—	—	—	trace	·8	—	3·4	—	—	trace
Trifolium repens............	37·2	43·6	38·6	*39·8*	38·6	24·4	34·0	30·8	*31·9*	24·0	26·0	23·8	*24·6*	11·6	5·1	*8·4*	46·3	19·4	6·3	4·2
Lotus corniculatus	—	—	—	—	—	—	—	—	—	—	—	—	—	·4	6·6	*3·5*	—	—	1·9	—
Achillea Millefolium	—	—	trace	—	trace	—	—	—	—	trace	—	·9	—	—	3·8	—	—	—	trace	—
Ranunculus sps.	·8	1·8	1·9	*1·5*	*	*	*	·5	—	3·1	1·0	2·8	*2·3*	5·1	4·5	*4·8*	*	4·5	*	2·2
Other weeds.................	trace	·5	trace	*trace*	·6	6·1	trace	1·4	*1·8*	·5	·6	11·3	*4·1*	4·1	19·1	*11·6*	7·5	3·1	31·3	trace
Bare surface.................	—	—	—	—	trace	·4	·3	—	*·2*	·5	trace	·8	*·4*	—	1·3	—	·6	·4	·5	1·1
Totals	100·0	99·1	99·8	—	96·7	99·1	99·5	99·9	—	99·5	99·4	99·1	—	98·9	97·2	—	99·3	96·7	95·7	99·8
Gramineae	62·0	53·2	59·3	*58·2*	57·5	68·2	65·2	67·2	*64·5*	71·4	71·6	59·5	*67·5*	77·7	56·0	*66·9*	41·5	70·3	55·7	92·1
Leguminosae	37·2	43·6	38·6	*39·8*	38·6	24·4	34·0	30·8	*32·0*	24·0	26·0	23·8	*24·6*	12·0	12·5	*12·3*	49·7	19·4	8·2	4·2
Other useful Plants.........	—	—	trace	—	trace	—	—	—	—	trace	—	·9	—	—	3·8	—	—	—	trace	—
Weeds .*.....................	·8	2·3	1·9	*1·6*	·6	6·1	trace	1·9	*2·1*	3·6	1·8	14·1	*6·5*	9·2	23·6	*16·4*	7·5	6·6	31·3	2·2

NOTE. An asterisk shows that the quantity of the species was not ascertained separately, but that it has been included in the totals at the foot of the table.

Change in Botanical Composition of Herbage caused by dry weather.

"Washpit" A, High-lying and dry. "Washpit" C, Low and moist. "Hall Close" A, Best section, dry. "Hall Close" B, Low-lying damp section.

Reference No.	13				4			
Name	"Washpit"				"Hall Close"			
Section	A		C		A		B	
Date of Examination	June 7th	July 28th	June 7th	July 28th	May 12th	Aug. 4th	May 12th	Aug. 6th
No. of places examined...	4	6	6	6	6	8	2	4
Lolium perenne	49·8	73·4	19·3	36·2	24·2	37·0	18·7	27·6
Dactylis glomerata	5·0	8·1	3·2	1·6	1·7	1·0	—	—
Cynosurus cristatus	8·2	·7	13·3	3·7	7·1	1·7	5·5	14·1
Alopecurus pratensis	—	trace	—	trace	—	—	—	—
Phleum pratense...........	3·7	2·2	1·9	1·4	3·4	2·0	2·0	2·3
Avena flavescens	1·4	trace	4·5	2·2	—	—	—	—
Poa trivialis	3·5	·7	2·8	1·0	4·9	1·3	5·6	1·8
Poa annua	·6	·6	—	—	1·8	trace	—	—
Festuca ovina	trace	trace	7·8	7·2	1·2	·7	·3	trace
Agrostis alba, var. stolonifera	2·3	8·5	1·7	6·6	7·6	11·3	12·0	13·0
Holcus lanatus	—	—	2·8	2·3	5·0	6·5	9·7	6·1
Trifolium repens...........	23·0	4·3	18·9	28·8	40·3	36·6	23·7	29·9
Achillea Millefolium	1·0	5·1	1·9	trace	—	trace	—	—
Ranunculus Ficaria	—	—	—	—	1·4	—	19·5	—
Ranunculus bulbosus	trace	—	5·5	trace	1·1	1·1	·3	trace
Bellis perennis..............	—	—	9·5	1·1	—	—	—	—
Mosses	—	trace	—	trace	—	—	—	—
Various weeds	1·3	—	6·8	5·3	trace	trace	2·7	3·4
Bare surface..................	—	·7	—	1·7	—	—	—	—
Totals	99·8	99·3	99·9	99·1	99·7	99·2	100·0	98·2
Gramineae	74·5	89·2	57·3	62·2	56·9	61·5	53·8	64·9
Leguminosae	23·0	4·3	18·9	28·8	40·3	36·6	23·7	29·9
Other useful Plants.........	1·0	5·1	1·9	trace	—	trace	—	—
Weeds	1·3	trace	21·8	6·4	2·5	1·1	22·5	3·4

Note. The effect of dry weather on white clover growing on dry soil is strikingly shown. The value of Yarrow as a drought-resisting plant is also indicated.

Variation of Botanical Composition of the Herbage during the Season.

Taking the average of ten fields which apparently were not affected to any great degree by their position or other circumstances, we find that during the months of May, June and July there was an increase in ryegrass and white clover to the extent of about 5 per cent. of the total herbage in each case. With weeds, crested dogstail and rough-stalked meadow grass there was a uniform decrease. In several instances the latter plant had almost disappeared by August.

The effect of drought is clearly seen in Table XI, which shows that on "Washpit" while white clover almost completely died away on the drier part, it increased considerably on the moister section.

Chemical Composition of the Herbage.

A study of Table XII shows that this varied very much with each type of pasture. For instance, in the herbage from "The Seeds" in May there was 1·73 per cent. more nitrogen and nearly twice as much phosphate as in the herbage from "Road Part" at the same date.

The analyses also indicate that some fields reached their best condition, as regards the quality of their herbage, earlier in the season than others. Thus herbage from "The Seeds," "Hall Close," and "Middle Welham" was richest in phosphate and nitrogen in early May, while the herbage of "Cow Close" and "Clock Close" appeared to be at its best three or four weeks later. Between the first week in June and the first week in August, however, there was in every instance a large increase in the dry matter, accompanied by a decrease in the percentages of nitrogen and phosphate.

Relation between the Botanical and Chemical Composition of the Herbage.

If these two series of analyses are compared it will be seen that the percentages of nitrogen and phosphate in the herbage appear to vary with the quantities of white clover and ryegrass present, especially with the former.

Nitrogen was determined in samples of each separate species from an old pasture (No. 10) in June. The percentages were: white clover 3·81, yarrow (*Achillea Millefolium*) 3·22, grasses (75 per cent. ryegrass)

TABLE XII. *Chemical Composition of Herbage and Soils of Pastures and Meadows in Leicester and Northamptonshire.*

Reference No.	1906	HERBAGE									SOIL										
		Early Season May 8th			Middle Season May 28th—June 4th			Late Season August 1st—9th													
	Name	Dry Matter	Nitrogen	P_2O_5	Dry Matter	Nitrogen	P_2O_5	Dry Matter	Nitrogen	P_2O_5	Date of Sampling	Depth of Sample, ins.	Moisture	Organic Matter and loss on ignition	Nitrogen	P_2O_5 Total	P_2O_5 Available	K_2O Total	K_2O Available	$CaCO_3$ Available	Insol. Residue
		%	%	%	%	%	%	%	%	%			%	%	%	%	%	%	%	%	%
1	"The Seeds"	19·4	4·45	1·070	21·2	3·60	1·025	38·0	2·73	·894	Oct. '05	8	3·94	11·88	·330	·798	·122	·952	·022	·340	62·10
3	"Cow Close"	20·4	3·88	·922	20·5	3·93	1·087	33·1	3·27	·775	,,	6	4·10	11·47	·366	·256	·028	·747	·011	·200	70·16
4	"Hall Close"	20·7	3·89	·900	21·5	3·52	·810	30·7	3·21	·805	,,	6	7·92	18·12	·577	·269	·019	·952	·010	·506	58·41
9	"Highfield"..	—	—	—	23·5	3·18	·900	49·6	2·04	·635	May '06	6	3·49	11·82	·358	·236	·018	·770	·026	·550	72·47
12	The "Big Field".........	—	—	—	23·0	3·18	·885	39·1	2·70	·841	,,	6	4·27	10·93	·356	·323	·021	·724	·011	·100	68·02
13	"Washpit," Sec. A......	—	—	—	13·2	3·47	·942	53·2	2·24	·645	,,	6	4·03	12·78	·418	·293	·028	·948	·042	·521	68·88
18	"Washpit," Sec. C	—	—	—	21·5	2·56	·757	57·6	1·97	·645	,,	6	4·18	12·95	·414	·312	·020	·670	·014	4·285	67·70
19	"Road Part"	28·0	2·72	·552	27·4	2·52	·742	56·0	1·87	·377	,,	5	4·61	14·42	·393	·162	·006	1·095	·030	·215	68·03
15	"Solstaceway"	—	—	—	25·1	2·34	·537	58·5	1·54	·347	Oct. '05	6	—	—	—	·180	—	·906	—	—	66·21
2	"Spence's Meadow" ...	—	—	—	17·1	3·08	·888	* 45·9	2·78	·817	—	—	—	—	—	—	—	—	—	—	—
18	"Clock Close"...........	30·0	2·26	·595	21·6	2·33	·690	47·8	1·70	·555	May '06	6	9·25	20·27	·574	·274	·022	1·100	·016	·250	45·17
11	"Top Meadow"	—	—	—	20·0	2·61	·752	* 42·6	2·16	·605	—	—	—	—	—	—	—	—	—	—	—
17	"Middle Welham"......	22·6	3·22	·670	22·0	2·85	·592	* 37·3	1·87	·392	—	—	—	—	—	—	—	—	—	—	—
7	"Watson's Seeds"	—	—	—	23·0	3·58	·988	48·0	2·42	·662	—	—	—	—	—	—	—	—	—	—	—
5	The "Old Churchyard"	—	—	—	18·1	3·77	1·003	51·7	2·82	·790	—	—	—	—	—	—	—	—	—	—	—
6	"Round Pond Field"..	—	—	—	22·0	3·55	·901	42·0	2·75	·925	,,	6	3·49	11·20	·310	·273	·020	·852	·010	·450	67·84
8	"Church Field".........	—	—	—	21·9	3·26	·884	39·5	2·71	·864	,,	6	4·94	13·00	·376	·260	·024	1·051	·028	·400	68·25
20	Cransley, Plot 6	—	—	—	†34·5	1·62	—	—	—	—	—	—	3·90	11·50	·295	·133	·013	·540	·008	—	68·30

* Aftermath. † June 21st.

2·53, and miscellaneous plants 2·14. These analyses indicate that white clover is probably the chief factor in determining the quantity of nitrogen in the herbage of a pasture.

RELATION BETWEEN SOIL AND HERBAGE.

On comparing the analyses of the soils with the chemical composition of the herbage there appears to be some relation between the quantity of available phosphates in the former and the percentages of nitrogen and phosphate in the latter. The soil of "The Seeds" contained an exceptionally high percentage of phosphates and its herbage was also very rich in phosphate and nitrogen. The herbage of this field and also of Nos. 3, 6, 8 and 13 sect. A, which are rich in phosphates, should be compared in this respect with the herbage of "Road Part" and "Solstaceway," which are comparatively poor in phosphates. Although chemical analysis shows that "Clock Close" is well supplied with phosphates, its herbage was shown by both botanical and chemical analysis to be of very poor quality. Poorness of the herbage here was evidently due to the bad mechanical condition of the soil, which made it unsuitable for the growth of the better pasture plants.

DENSITY OF HERBAGE.

It is of course evident that the value of a pasture depends not only upon the quality of its herbage but also upon the quantity produced in a season. This will depend to a considerable extent upon the density of the turf, *i.e.* the closeness of growth of the plants. By cutting away the edible herbage from a measured area in a number of places and weighing, the density of the herbage on each type of pasture could be roughly compared.

The results showed that with herbage about one inch in length the weight per square foot varied from 50 grams on a new pasture with a very open turf (Field 19, Univ. Farm), and 75 grams on types *b* and *c* (page 292), up to 85 or 95 grams on the densest turfs, *e.g.* Nos. 1 and 4.

These figures roughly indicate a large difference in the weight of herbage available per acre for grazing on each type of pasture.

TABLE XIII. *Approximate number of Plants on different types of Pastures.*

The figures show thousands of plants per acre.

Reference No.	1	3	9	12	17	19	20	8	6	14	New Pastures, University Farm			
Name	"The Seeds"	"Cow Close"	"High-field"	"The Big Field"	"Middle Wel-ham"	"Road Part"	Cransley Plot 6	"Church Field"	"Round Pond Field"	"Un-win's Pasture"	Field 19	Field 16, Elliots's Mixture	Field 16	Field 18, Un-manured
Date of Counting	May '06	May '06	May '06	June '06	May '06	May '06	June '06	June '06	June '06	Oct. '05	Sept. '05	Sept. '05	Apr. '06	June '06
No. of turfs examined	2*	2*	2*	2*	3†	2†	2*	2*	2*	1*	6†	6†	4†	4†
Lolium perenne	1730	3306	1783	1435	739	739	130	2000	1262	2740	1742	1546	1957	1044
Dactylis glomerata	—	—	478	—	348	217	391	43	—	585	319	261	261	174
Cynosurus cristatus	344	1131	565	1174	1218	1300	3262	1044	783	—	7	188	130	87
Alopecurus pratensis	43	87	—	—	87	—	—	—	—	261	14	14	—	43
Phleum pratense	215	348	609	348	43	—	—	739	—	—	94	72	87	130
Avena flavescens	—	—	348	—	565	304	435	—	—	—	—	21	67	43
Poa trivialis	1807	1522	3436	2132	174	68	—	5829	3915	1566	14	58	—	43
Poa pratensis	—	—	—	—	—	—	43	—	—	—	—	14	—	—
Poa annua	3828	—	—	217	—	—	—	87	174	—	—	—	43	—
Festuca elatior var. pratensis	—	—	—	—	—	—	—	—	—	—	130	225	87	130
Festuca ovina et vars.	—	130	—	—	130	348	565	391	261	1566	79	145	174	87
Agrostis alba et vars.	522	870	3175	783	957	560*	87	870	700	—	87	29	—	174*
Holcus lanatus	—	261	—	913	87	87	478	609	740	—	—	—	—	—
Anthoxanthum odoratum	—	—	—	130	130	87	—	—	—	—	—	—	—	—
Agropyrum repens	—	—	—	—	43	43	20	—	—	—	36	14	43	330*
Hordeum pratense	—	—	—	—	—	—	—	—	—	913	—	—	—	—
Trifolium pratense	—	—	—	—	—	—	—	—	—	—	58	87	43	43
Trifolium repens	11832	12093	6177	12789	739*	174*	1740	13920	15007	174	196	130	261	1392*
Trifolium hybridum	—	—	—	—	—	—	—	—	—	—	58	7	20	—
Trifolium minus	—	—	—	—	—	—	130	—	—	—	—	—	—	—
Lotus corniculatus	—	—	—	—	43	130	—	—	—	—	—	—	—	—
Medicago lupulina	—	—	—	—	—	—	350	—	—	—	—	7	—	—
Other useful plants	—	—	—	—	—	435	—	—	—	—	21	317	43	552
Ranunculus spp.	478	478	130	304	—	783‡	—	—	43	891	—	—	—	—
Bellis perennis	—	—	—	—	—	174	1392	—	—	870	—	—	—	—
Plantago lanceolata	—	—	—	—	—	220	696	—	—	—	—	36	—	—
Luzula campestris	—	—	—	—	—	1087	—	—	—	—	—	—	—	—
Other weeds	—	43	348	130	2914	700	6525	—	43	348	26	94	43	304
Totals in Millions	20·8	20·1	17·1	20·3	8·2	7·4	16·2	25·5	22·9	9·4	2·9	3·2	3·2	5·1
Gramineae	8·5	7·6	10·4	7·1	4·5	3·7	5·4	11·6	7·8	7·6	2·6	2·6	2·9	2·8
Leguminosae	11·8	12·0	6·2	12·8	·8	·3	2·2	13·9	15·0	·2	·3	·2	·3	1·4
Other useful Plants	—	—	—	—	—	·4	—	—	—	—	—	·3	—	·6
Weeds	·5	·5	·5	·4	2·9	3·0	8·6	—	·1	1·6	—	·1	—	·3

NOTES. Each turf was one square foot in area. Those marked thus * were lifted, and each separate rooting of white clover or of grasses spreading by

NUMBER OF PLANTS PER ACRE.

In Table XIII is given the approximate number of plants per acre on several of the fields already mentioned.

There was no difficulty in counting the plants on the new pastures without lifting the turfs, but on most of the best pastures near Market Harborough the close and interwoven growth of the plants made it almost impossible to count them even when the turfs were lifted. In these latter cases, therefore, after lifting, each separate rooting of white clover and of creeping grasses, such as rough-stalked meadow grass and fiorin, was counted as one "plant."

On fields 16 and 19 (Univ. Farm), where the limits of each plant could be readily defined, the results show that on such new pastures not more than about three or four million individual plants per acre may be present. Counting every distinct rooting of a plant on the old pastures did not of course give any accurate idea of the number of individuals present. The figures obtained, however, serve for comparison and indicate the limit to the number of individuals which can exist per acre in a pasture.

In concluding, our best thanks are due to all those gentlemen who kindly allowed us to make use of their fields in doing this work; especially to Mr E. Fisher, Market Harborough, and to Mr John Berry, of Slawston, whose knowledge of the district greatly assisted in the choice of suitable fields.

SUMMARY.

The following is a brief summary of the more important points which our investigations so far appear to have given us:—

1. That white clover and ryegrass form by far the greater part of the herbage on the best grazing lands—both old and recent in the English Midlands—and that the next most abundant species on these pastures are usually crested dogstail, fiorin (*A. stolonifera*), and rough-stalked meadow grass.

2. That the herbage of the inferior types of grass land in the same district consists very largely of bent grass (*A. vulgaris*) and various weeds, while white clover and ryegrass are present in comparatively small quantities.

3. That the only other species of grasses which are occasionally abundant in these pastures are:—cocksfoot and sheep's fescue in the better fields; Yorkshire fog and tufted hair-grass in the poorer ones.

4. That the herbage of a pasture varies botanically to a considerable extent during a season, this variation being however determined very largely by soil, situation and weather.

5. That the choicest grazing land is invariably associated with soil rich in available phosphates.

6. That on soils suitable for permanent pasture, inferiority of the herbage is generally due either to (1) a deficiency of available phosphates, or (2) to their bad mechanical condition.

7. That herbage of the best grazing land may be twice as rich in nitrogen and phosphate as that of a poor pasture, and that this large difference appears to be directly determined chiefly by the proportion of white clover present, and indirectly by the percentage of available phosphates in the soil.

8. That from the early part of June onwards the percentage of nitrogen and phosphate in the herbage of a pasture gradually decreases, while the proportion of dry matter rapidly increases.

9. That the quantity of herbage available per acre for grazing depends much upon the density of the herbage; and that no plants appear to be more capable of producing a dense growth of herbage than white clover and ryegrass, providing the soil is suitable for them.

10. That the number of individual plants per acre on the best old pastures, and necessary for the production of a thick close turf, is probably very much less than is usually supposed.

OXIDATION IN SOILS, AND ITS RELATION TO PRODUCTIVENESS.

PART II. THE INFLUENCE OF PARTIAL STERILISATION.

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IT was shown in an earlier communication[1] that the absorption of oxygen by soil is mainly brought about by the action of micro-organisms, and is greatly diminished if the soil has previously been heated to 120° C. On one occasion the temperature of the steriliser only rose to 95°, and it was found that the rate of oxidation of the soil, instead of being reduced, was considerably increased. This unexpected result led to experiments with other methods of partial sterilisation, such as exposure to vapours of toluene, chloroform, etc., and in each case the same effect was produced, the amount of oxygen absorbed showed a marked increase after the antiseptic was removed.

Reasons were adduced in the previous paper for supposing that the rate of oxidation affords a measure of the activity of the soil micro-organisms. If this supposition is well founded we are forced to conclude from the more rapid oxidation that partially sterilising a soil so increases the activity of the surviving organisms that they use up more oxygen, and presumably bring about more decomposition, than the original organisms.

The composition of the crop affords clear evidence that the availability of the plant food in the soil has been increased by partial sterilisation. In the case of heated soils this might well have been brought about by chemical decomposition, but where volatile antiseptics were used it is difficult to see what purely chemical change can have taken place; the simplest view, and the one best agreeing with all our observations, is that the increased availability is connected with the changed bacterial flora.

[1] This *Journal*, Vol. I. 1905, p. 260.

Partial sterilisation brings about a gain in crop, and there can be little doubt that this is mainly, if not entirely, due to the extra availability of the plant food.

Our experiments show that it is possible to increase, for a time at any rate, the amount of food the plant gets from the soil.

These experiments were made at the South Eastern Agricultural College, Wye.

Effect of partial sterilisation on the rate of oxidation.

A. Experiments with volatile antiseptics.

Ten gram lots of soils were exposed for a time (generally three days) to vapours of the antiseptic, then transferred to tubes plugged with cotton-wool through which a current of washed and filtered air was drawn for 24 hours. This treatment appears to remove all the antiseptic; we were unable to detect any by smell, or, in the case of carbon disulphide, by the very sensitive triethylphosphine test. The control soil was put through precisely the same process, excepting that air was substituted for antiseptic vapour. It is very important in these experiments to make all the conditions as nearly alike as is possible. Finally the soil was put into the oxidation apparatus already described[1] and moistened with 20 per cent. of water. The amount of oxygen taken up is indicated by the rise of mercury in the gauge tube. As the experiments are only intended to be comparative it is not necessary to determine the absolute amount absorbed; for our present purpose it suffices to express the results in arbitrary units.

The soils were all from well-manured plots, one was a sand, two others were loams, and the fourth contained so much calcium carbonate that its rate of oxidation was abnormally high. Certain analytical data for the four soils are given below.

TABLE I.

Percentages calculated on soil dried at 100°.

		Loss on ignition	N	$CaCO_3$
Soil 1.	Sandy soil	3·37	·135	·39
Soil 2.	Loam, College hop garden	3·94	·170	10·7
Soil 3.	Loam, garden	6·19	·236	8·9
Soil 4.	Chalky soil, College farm		·140	59·3

The rates of oxidation are given in Table II.

[1] This *Journal*, Vol. I. 1905, p. 262.

TABLE II.

Rates of oxidation of untreated and of partially sterilised soils.

	mm. of oxygen absorbed in			Relative amounts, untreated = 100		
Soil 1. Sandy soil.	3 days	6 days	9 days	3 days	6 days	9 days
Untreated soil	3·1	7·2	11·3	100	100	100
Soil treated with carbon disulphide	9·3	17·8	20·8	300	247	184
,, ,, toluene	7·7	15·0	18·7	248	208	165.
,, ,, chloroform	5·0	13·3		161	184	
Soil 2. College hop garden. Experiment 1.						
Untreated soil	2·7	5·5	6·0	100	100	100
Soil treated with carbon disulphide	7·2	9·9	11·8	267	181	197
,, ,, toluene	8·7	12·2	15·0	322	222	250
,, ,, chloroform	7·8	11·6	13·0	289	212	218
Experiment 2. Another sample of the same soil.						
Untreated soil	13·0	21·5	27·7	100	100	100
Soil treated with carbon disulphide	17·0	21·3	26·4	131	99	95
,, ,, toluene	14·1	22·3	29·2	110	104	105
,, ,, chloroform	17·3	23·5	30·8	133	110	111
Soil 3. Garden soil.						
Untreated soil	9·4	12·3	13·8	100	100	100
Soil treated with carbon disulphide	23·5	27·9	28·3	250	227	205
,, ,, toluene	12·8	24·7	27·1	136	201	196
,, ,, chloroform	10·1	15·3	16·0	108	125	116
Soil 4. Chalky soil.						
Untreated soil	5·2	8·6	13·1	100	100	100
Soil treated with carbon disulphide	5·2	11·2	19·7	100	130	151
,, ,, toluene	5·4	12·5	20·6	104	145	157
,, ,, chloroform	10·2	12·3	15·4	196	143	118
Experiment 3. Another sample of the same soil.						
Untreated soil	3·9	5·9	8·0	100	100	100
Soil treated with carbon disulphide	17·1	21·4	23·9	439	363	299
,, ,, toluene	2·0	8·5	12·2	52	144	153
,, ,, chloroform	1·3	4·8	6·3	33	81	79

The readings for the duplicate untreated soils agree to within about 1 mm.

Each soil was made the subject of several experiments. Two sets of results are given for soils 2 and 4: they are fairly typical of the rest. They are not directly comparable, because they were not obtained at the same time or under the same temperature conditions, but they show clearly that the figures must be interpreted in a qualitative way only and have no quantitative significance, a fact which is also demonstrated by the variation in the relative rates from day to day. Sometimes one antiseptic and sometimes another has been found most potent, occasionally no difference in the rate has been produced, and it has happened that the rate has been depressed by the treatment. But

taking the results as a whole it is quite evident that the rate of oxidation has been increased by partial sterilisation.

Apparently it is not essential to draw a current of air over the soil for 24 hours, though we always considered it desirable to do so. In one experiment the soil after removal from the antiseptic vapour was exposed for three minutes only to air and then transferred to the oxidation apparatus. It is practically certain that some trace of the antiseptic must have remained, yet the rate of oxidation increased considerably.

The results are given in Table III.

TABLE III.

Rates of oxidation when traces of the antiseptic were probably present.

	mm. of oxygen absorbed in			Relative amounts, untreated = 100		
	3 days	6 days	8 days	3 days	6 days	8 days
Untreated soil	3·4	2·9	4·1	100	100	100
Soil treated with carbon disulphide	6·8	6·3	8·7	200	217	212
,, ,, toluene	6·4	7·3	11·5	188	252	280
,, ,, chloroform	11·1	11·6	14·5	326	400	354

It does not appear to be possible to sterilise a soil completely by treatment with any of these antiseptics.

Some experiments have also been made with formalin. This differs from the other antiseptics because it cannot be completely removed from the soil; apparently polymerisation or some combination with a soil constituent takes place. The rate of oxidation is very considerably reduced, often indeed to zero.

B. Experiments with non-volatile antiseptics.

Ten grams of soil were mixed with small quantities of various poisons either by grinding in a mortar or by adding solutions of the proper strength. There are difficulties about either method. Grinding increases the rate of oxidation, probably by effecting a better distribution of the organisms or their food-stuffs, and it is hardly possible to ensure the same amount of grinding for all the soils. On the other hand, it is quite impossible to secure uniform distribution of a dissolved body in the soil owing to the property soils have of withdrawing substances from their solutions. We have usually found that grinding gives more even results.

Copper sulphate and mercuric chloride have been used in various strengths and the results are given in Table IV. It will be observed that very small amounts have no effect, while larger quantities check oxida-

tion. In some experiments there is evidence of a slight stimulating effect when about ·01 per cent. of poison is present, but this is not always the case, and we have not been able to discover the conditions under which the stimulus shows itself.

The amount of poison which may be present in the soil without retarding oxidation is very remarkable; even 0·1 per cent. of mercuric chloride does not inhibit it and yet it would effectually sterilise a solution. The explanation appears to be that the poison does not get really into the soil in spite of the grinding and the subsequent addition of 20 per cent. of water, and hence many of the organisms escape.

TABLE IV.

Rates of oxidation of soils treated with non-volatile poisons.

Copper sulphate and hop garden soil.

Amount of copper sulphate	mm. of oxygen absorbed in 3 days	6 days	9 days	Relative amounts, untreated = 100 3 days	6 days	9 days
None	6·7	12·7	15·1	100	100	100
·01 per cent.	6·3	12·4	14·9	94	98	99
·1 "	4·5	11·0	14·4	67	87	95
1 "	4·1	8·4	10·5	61	66	69

Copper sulphate and gault pasture soil.

Amount of copper sulphate	mm. of oxygen absorbed in 3 days	6 days	9 days	Relative amounts, untreated = 100 3 days	6 days	9 days
None	10·3	17·5	26·6	100	100	100
·001 per cent.	12·6	20·2	28·9	122	115	109
·01 "	13·8	18·5	29·2	134	106	110
1 "	2·2	3·7	8·2	21	21	31

Mercuric chloride and fertile arable soil.

Amount of mercuric chloride	mm. of oxygen absorbed in 3 days	6 days	10 days	13 days	Relative amts. untreated = 100 6 days	10 days	13 days
None	2·9	7·3	10·3	13·6	100	100	100
·001 per cent.	3·8	7·0	9·9	15·3	96	97	123
·01 "	3·9	9·3	12·4	13·8	127	120	100
·1 "	2·1	2·0	2·8	4·3	29	27	32
1 "	nil	nil	nil	?	nil	nil	?

Mercuric chloride and hop garden soil.

Amount of mercuric chloride	mm. of oxygen absorbed in 5 days	8 days	11 days	14 days	Relative amts. untreated = 100 5 days	8 days	11 days	14 days
None	8·0	10·2	13·3	17·2	100	100	100	100
·001 per cent.	5·1	9·0	12·7	14·5	64	88	95	84
·01 "	1·7	4·4	7·0	7·8	21	43	53	57
·1 "	1·1	1·2	1·5	4·1	14	12	12	24

C. Experiments with heated soils.

In our first experiments the soil and the whole oxidation apparatus were heated in a steam-oven to 95° for two hours, but later on it became evident that there was no advantage gained by including the apparatus, and the soil only was heated. The results, given in Table V, show

clearly that the effects of heating to 95° is to considerably increase the rate of oxidation.

TABLE V.

Rates of oxidation of heated soils.

	mm. of oxygen absorbed in			Relative amounts		
	3 days	6 days	9 days	3 days	6 days	9 days
Hop garden soil, unheated ...	3·7	5·2	7·0	100	100	100
,, ,, heated to 95°	6·0	8·2	12·0	160	158	171
Garden soil, unheated	7·5	10·2	15·5	100	100	100
,, heated to 95°......	16·9	27·2	33·2	226	267	215

Effect of partial sterilisation on productiveness.

Earlier investigations. That carbon disulphide favourably influences plant growth has long been known. Girard[1] had used it in France to clear a piece of sugar-beet ground badly infested with nematodes, and observed marked increases in the succeeding crops; and Oberlin, an Alsatian vine-grower, who had long used carbon disulphide for killing phylloxera[2], noticed that it also increased the productiveness of the soil. These results, published independently in 1894, drew general attention to the subject, the experiments were repeated, confirmed and extended, and a number of papers have since appeared. From the practical side Behrens[3] showed that application of carbon disulphide doubled the crop on "onion sick" ground; Mach[4] found that 200 grams per square metre augmented the yield of oats, potatoes and beets, and Henry[5], using double this quantity, obtained large increases in the growth of acacias and other plants.

Pot experiments were made by Pagnoul[6], and also by Koch[7] who found that the effect increased up to a certain point with increasing amounts of carbon disulphide:—

CS_2 per pot, c.c.	0	25	60	100	200	300
Yield of mustard, grams	13·25	14·92	21·83	18·68	37·58	22·3
,, buckwheat, grams	36	79	94	93	99	90

[1] *Bulletin de la Société Nationale d'Agriculture en France,* 1894, Vol. 54, p. 356.

[2] *Bodenmüdigkeit und Schwefelkohlenstoff,* Mainz, 1894, Zabern: also *Journal d'Agriculture pratique,* 1895, 1, 459. Carbon disulphide appears to have been used as an insecticide 50 years ago in Algeria for destroying grain pests, v. Akbar, 1857, Oct. 16, quoted in *Gardeners' Chronicle,* 1858, Aug. 28, 653.

[3] Koch's *Jahresbericht über die Fortschritte in der Lehre von den Gärungsorganismen,* 1895, 6, 280.

[4] *L'Engrais,* 1896, 548.

[5] *Bul. Soc. Sci. Nancy,* 1901, 27, abs. in *Expt. Station Record,* 1902, 13, 528.

[6] *Annales Agronomiques,* 1895, 21, 497.

[7] *Arbeiten der deutschen Landwirtschafts-Gesellschaft,* Heft 40, 1899.

Wollny's[1] pot experiments also showed a gain in crop, and, more recently, Nobbe and Richter[2] have obtained similar results with ether, chloroform and benzene.

Weight of oats, dry matter in grams.

	Untreated soil	Soil treated with ether	CS_2	$CHCl_3$	C_6H_6
I.	26·16	34·26	41·39	37·13	40·78
II.	29·75	35·19	36·40	34·01	35·77

Experiments on heated soils. The earliest observations on the effect of heat on soil arose out of bacteriological investigations. It had at first been assumed that no change took place, but Franke[3] in 1888 demonstrated the incorrectness of this view and obtained larger crops of oats and of yellow lupines on heated than on unheated soil; he showed also that heating increased the solubility of the mineral and of the organic matter in the soil. Five years later Liebscher[4], who was engaged in one of the periodical revivals of the question whether plants can assimilate free nitrogen, stated that the sterilisation of soil by steam increases the availability of the phosphates and nitrogen compounds. Later experiments have confirmed this, but do not take us much further. Pfeffer and Franke[5], working with mustard, confirmed the gain in productiveness and obtained an increased assimilation of nitrogen, which suggests that the nitrogen compounds have become more available.

	Unmanured soil		Soil + $NaNO_3$	
	Unsterilised	Sterilised	Unsterilised	Sterilised
Weight of crop	14·8	27·6	62·4	71·2
Weight of N taken up	·1546	·4323	1·1938	1·4688

Krüger and Schneidewind[6] carried out a somewhat fuller series of experiments and strikingly demonstrated the effect on the availability of the mineral matter. This soil evidently stood in no need of nitrogenous manure, but was lacking in mineral food-stuffs, and a gain

[1] *Vierteljahrsschrift d. bayerischen Landwirtschaftrats*, 1898, Heft 3, 319, abs. in *Bied. Centr.* 1900, 29, 146.

[2] *Landwirtschaftlichen Versuchs-Stationen*, 1904, 60, 433.

[3] *Berichte der Deutschen botanischen Gesellschaft*, 1888, 89, 6 (Generalversammlungs Heft).

[4] *Deutsche Landw. Presse*, 1893, No. 94, 976. Liebscher and Wagner were, on this occasion, the two protagonists, and discussion continued for some time in the *Deutsche Landw. Presse.*

[5] *Landw. Versuchs-Stat.* 1896, 46, 117.

[6] *Landw. Jahrbücher*, 1899, 28, 224.

in crop was produced when these were either added or set free by heat.

	Weight of mustard			
	No manure	$NaNO_3$	Complete mineral manure	$NaNO_3$ + complete mineral manure
Untreated soil ...	17·3	17·5	33·7	50·9
Sterilised soil ...	33·2	36·5	46·9	62·4

Dietrich[1] also obtained increased productiveness when working with arable and garden, but not with pasture soils. He concluded that when the soils are heated there arises some poisonous substance to which mustard is very sensitive, whilst oats, buckwheat, and peas are much less so. An amplified account was given by C. Schulze in 1906[2].

Koch and Lüken[3] obtained very similar results with oats grown on a very poor sand containing only ·016 per cent. of nitrogen. Equal amounts of nitrate of soda were supplied to the sterilised and to the unsterilised pots, but the plant got more nitrogen from the former than from the latter. The authors suggest that nearly 10 per cent. of the nitrogen of the sterilised sand was taken up.

Practical horticulturalists have for some time used steam for killing insect pests, nematodes, etc., in greenhouse soils, and there are several records of gains in the rate of plant growth. Stone and Smith of the Hatch Experiment Station, Massachusetts, dealt with the subject in 1898[4] and at a later date[5] recommended heating greenhouse soil for the sake of the extra crop obtained.

Our experiments. We have made a number of pot experiments, usually with soil 2 (College hop garden), in the glass-house attached to the laboratory. One or two hundredweights of soil which had passed a half-inch sieve was carefully turned half a dozen times in the manner adopted by the horticulturalist for mixing potting soils, and at the same time all earthworms, insects, etc., were picked out. The pots used were Doulton's glazed stoneware jars of two gallons capacity, technically known as mixing pans, they were filled with equal weights of soil (usually 16 kilos), and samples were drawn from each pot for determination of the amount of nitrate and of water present. This gives a ready means of ascertaining whether the soil is uniform in composition, though

[1] *Jahresbericht der landw. Versuchs.* Marburg, 1901-2, p. 16, abs. in *Bied. Centr.* 1903, 32, 68.

[2] *Landw. Versuchs-Stat.* 1906, 65, 137.

[3] *Jour. für Landw.* 1907, 55, 161.

[4] *Mass. Hatch Station Bul.* 55, see *Expt. Station Record*, 1899, 10, 1055.

[5] *Report of Hatch Station*, Mass., 1903, p. 38.

of course it does not indicate whether the packing is the same in all pots. The soil was then partially sterilised by one of the methods described below.

No manure of any sort was added.

After treatment, and before sowing, the pots in each series were brought to the same degree of moistness by adding the proper quantity of water, and they were all kept equally moist during the experiment. Sterilised tap-water was used throughout.

TABLE VI.

Weight and composition of crops grown in soils treated with volatile antiseptics.

(*a*) *Buckwheat* (April 9th to June 19th, 1907)

	Dry matter of crop, gms.	Relative weights of dry matter	Composition of dry matter N per cent.	P_2O_5 per cent.	K_2O per cent.
Untreated soil	18·14	100	2·75	1·87	5·62
Soil treated with $CHCl_3$	25·08	138	2·91	2·45	5·65
" " CS_2	23·27	128	3·15	2·34	5·97
" " toluene	20·98	116	3·00	2·12	5·79

	(*b*) *Buckwheat* (April 23 to July 15, 1906) Total wt. of crop, gms.	Dry matter of crop gms.	Relative weights of dry matter	(*c*) *Mustard* (May 22 to July 14, 1906) Total wt. of crop, gms.	Dry matter of crop, gms.	Relative weights of dry matter
Untreated soil	80·6	15·9	100	39·88	8·00	100
Soil treated with $CHCl_3$	105·2	23·0	143·8	50·4	9·9	124
" " CS_2	114·3	27·2	171·1	50·96	9·48	118
" " toluene	—	—	—	43·44	8·9	111
" " ether	89·0	19·3	121·4	—	—	—
" " benzene	—	—	—	46·4	9·7	121

Details of Experiment (*a*).

No. of pot	Treatment	N in dry soil per cent.	Total weight of crop, gms.	Dry matter of crop, gms.	Composition of dry matter N per cent.	P_2O_5 per cent.	K_2O per cent.
57	untreated	·163	189·25	18·75	2·85	1·90	6·63
75	"	·161	147·85*	17·53	2·65	1·83	4·61
55	chloroform	·159	228·7	27·52	3·06	2·52	5·39
56	"	·156	197·50	22·65	2·76	2·38	5·91
59	carbon disulphide	·159	198·2	21·52	2·98	2·23	6·20
76	" "	·161	224·5	25·02	3·33	2·56	5·75
58	toluene	·164	149·5	18·11	3·06	1·92	5·56
74	"	·166	220·6	23·85	2·96	2·32	6·03

* 75 was cut some hours later than 57, and had lost water in the meantime.

We are indebted to Mr E. C. Chapelow, the College horticulturalist, for much assistance with the management of the plants.

A. Experiments with volatile antiseptics.

A definite amount (25 or 50 c.c.) of the antiseptic having been poured into the soil, the pot was covered up and left for a week. The soil was then spread in a thin layer and stirred at frequent intervals until 36 hours after all smell of the substance had passed off; this usually took about three days. The unsterilised soils were spread out and stirred in precisely the same manner.

TABLE VII.

Residual effect of volatile antiseptics.

Experiment 1.		Untreated soil	Soil treated with $CHCl_3$
(*a*) *1st crop, Turnips* (Aug. 29, 1905 to Feb. 18, 1906)	Fresh weight	126·3	225·0
	Dry matter	13·0	25·25
	Relative weights of dry matter	*100*	*194*
(*b*) *2nd crop, Wheat* (Feb. 20 to July 26, 1906)	Straw	22·5	27·9
	Relative weights	*100*	*124*
	Grain	7·98	8·75
	Relative weights	*100*	*107*
(*c*) *3rd crop, Buckwheat* (Aug. 16 to Oct. 20)	Dry matter	6·15	5·75
	Relative weights	*100*	*94*
(*d*) *4th crop, Rye* (Dec. 21, 1906 to July 27, 1907)	Straw	49·45	32·28
	Relative weights	*100*	*65*
	Grain	16·4	19·2
	Relative weights	*100*	*117*

Experiment 2.	(*e*) *1st crop, Mustard* (Aug. to Oct. 1906)			(*f*) *2nd crop, Rye* (Dec. 1906 to July, 1907)			
				Grain		Straw	
	Green weight, gms.	Dry matter, gms.	Rel. wts. of dry matter	gms.	Relative weights	gms.	Relative weights
Untreated soil	118·0	18·12	100	11·48	100	29·05	100
Soil treated with $CHCl_3$	150·5	23·15	127·7	14·46	126	40·00	135
„ „ CS_2	117·6	19·81	109·4	15·33	133	41·04	141
„ „ toluene	123·3	21·11	116·5	14·55	127	34·40	119

Percentage composition of dry matter of Rye, Experiment 2 (*f*)

	Grain		Straw	
	N per cent.	P_2O_5 per cent.	N per cent.	P_2O_5 per cent.
Untreated soil	1·15	1·041	·517	·387
Soil treated with $CHCl_3$	1·15	·939	·588	·395
„ „ CS_2	1·28	1·094	·588	·542
„ „ toluene	1·29	1·095	·521	·468

The results of the experiments, and the dates of sowing and harvesting, are set out in Tables VI and VII. In one instance all the

figures are given to show the magnitude of the experimental error: in other cases mean values only are given.

The duplicate untreated pots agree to within 5 or 7 per cent. but the duplicate treated pots show much larger differences—20 to 27 per cent.—and repetition of the experiment usually places the antiseptics in a different order.

The results have no precise quantitative significance but are to be interpreted qualitatively, just as was the case for the rates of oxidation. What they do show is that partial sterilisation of the soil with volatile antiseptics causes an increase in crop. Pot experiments with other plants, spinach, cabbage, etc., and field trials with certain market garden crops, give similar results.

The action extends over more than one crop: there is a distinct residual effect seen in the second, but not in the third, crop. In one experiment turnips were followed successively by wheat, buckwheat, and rye without any further treatment whatsoever; in another experiment rye was taken after mustard. The results are given in Table VII.

Experiments with formalin. Although the soil was exposed to air for some time the formalin was not entirely removed, and it had a remarkable effect on the growth of turnips, the only crop yet tried. Germination was greatly retarded, and when finally the young plants appeared they were weak and a number died. After some weeks, however, the survivors picked up very rapidly and growth continued vigorously to the end. The results were:—

	Green weight, grms.	Dry matter	Relative weights of dry matter
Untreated soil	40·4	6·4	100
Soil treated with formalin...	68·4	16·0	250

B. Experiments with non-volatile antiseptics.

Kilogram lots of the soil were thoroughly mixed in a mortar with the proper quantity of the substance under investigation. The control soil was also put through an identical stirring process. The soils were then replaced in the pots, the requisite amount of water added, and the seeds sown.

The antiseptics used have been mercuric chloride, copper sulphate and the milder poison thymol. The results are given in Table VIII., they differ fundamentally from those obtained with volatile antiseptics for in no case has increased productiveness been observed.

We cannot explain the abnormally low result shown by buckwheat with ·001 per cent. of thymol.

TABLE VIII.

Crops grown in soils mixed with non-volatile antiseptics.

(*a*) *Mercuric chloride.* Buckwheat, sown Aug. 3rd, 1906, pulled Oct. 5.

Mercuric chloride added	1 per cent.	0·1 per cent.	·01 per cent.	·001 per cent.	none
Total weight of crop ...	nil	1·95	28·0	60·75	75·85
Weight of dry matter ...	nil	·33	5·55	13·25	14·7

(*b*) *Copper sulphate.*

		Untreated soil	·01 per cent. copper sulphate
Oats (Nov. 1, 1905 to July 5, 1906)	Straw...............	23·8	23·7
	Grain	11·4	13·5
Maize (Nov. 2, 1905 to July 5, 1906)	Dry matter	41·0	43·0

(*c*) *Thymol.*

		Untreated soil	·01 per cent. thymol	·001 per cent. thymol
Oats (as above)	Straw	23·8	19·3	19·8
	Grain	11·4	11·9	11·9
Maize (as above)	Dry matter......	41·0	43·0	43·0

Buckwheat, sown Aug. 27, 1906, pulled Oct. 5.

Thymol added	0·1 per cent.	·01 per cent.	·001 per cent.	none	none
Total weight of crop	11·2	28·30	22·30	31·51	29·00
Weight of dry matter ...	·8	2·82	1·43	3·42	2·90

C. Experiments with heated soils.

The pots were placed for two to three hours in a galvanised iron vessel through which a rapid current of steam was passed, giving a temperature of about 90° to 95° C. After they had cooled, they were brought to the same water content as the untreated pots. The increase in crop is very striking, as is seen by the results in Table IX.

With the exception of dwarf beans leguminous crops show no increase. No nodules form in the heated soils. Some of our experiments show that it is easier to get a second crop of a leguminous plant from a heated than from an unheated soil.

TABLE IX.

Crops grown in heated and in unheated soils.

(*a*) *Wheat*[1].

	Weight of crop				Composition of crop				
	Straw		Grain		Straw			Grain	
	Grms.	Rel. wts.	Grms.	Rel. wts.	N per cent.	P_2O_5 per cent.	K_2O per cent.	N per cent.	P_2O_5 per cent.
Unheated soil ...	36·23	100	10·02	100	·287	·361	1·89	1·89	·94
Heated soil	80·08	221	36·3	300	·341	·507	2·03	1·95	·95

[1] Grown in hop garden soil, containing ·161 per cent. N.

Various non-leguminous crops[1].

		Unheated soil Grms.	Heated soil Grms.	Relative weight, unheated = 100
1. Spinach,	green weight.........	10·55	47·2	449
	dry matter	1·7	6·45	379
2. Tobacco plant,	green weight.........	66·6	169·8	255
	dry matter	9·9	31·2	315
3. Tomato,	green weight.........	49·2	189·5	385
	dry matter	7·0	28·3	404
4. Verbena,	green weight.........	24·9	100·5	403
	dry matter	5·6	26·8	479
5. Turnips,	green weight.........	96·8	154·8	160
	dry matter	12·4	18·0	145
6. Lettuce,	green weight.........	128·6	170·7	133
	dry matter	10·24	17·25	168

(*c*) *Leguminous plants.*

		Unheated soil Grms.	Heated soil Grms.	Relative weight, unheated = 100
1. Sweet peas,	green weight.........	180	173	96
	dry matter	44	34	77
2. „ „	green weight.........	59·45	61·2	103
	dry matter	7·3	8·4	115
3. Dwarf beans,	green weight.........	66·0	134·4	204
	dry matter	9·0	21·6	240
4. Red clover,	green weight.........	16·6	15·8	95
	dry matter	3·35	3·1	92
5. Sainfoin	green weight.........	26·75	26·49	98
	dry matter	6·35	6·17	97

There is a distinct residual effect. Three sets of experiments have been made to test this point, and in each case the second, and in one case the third crop shows an increase.

TABLE X.

Residual effect shown by heated soils.

(*a*) Soil steamed Dec. 13th, 1906, sown with mustard Dec. 20th, this was pulled April 11th, 1907, and without further treatment Buckwheat was sown April 12th and pulled June 17th.

	Weight and composition of crop							
	1st crop. *Mustard*				2nd crop. *Buckwheat*			
		Composition of dry matter				Composition of dry matter		
	Dry matter, grms.	N per cent.	P_2O_5 per cent.	K_2O per cent.	Dry matter, grms.	N per cent.	P_2O_5 per cent.	K_2O per cent.
Unheated soil (mean of 2)	15·88	2·30	1·00	4·20	13·79	1·24	2·38	4·03
Heated soil (mean of 4) ...	24·33	4·43	2·08	5·02	27·40	2·00	2·26	4·74

[1] 1 to 4 were grown in arable soil containing ·110 per cent. N and losing 4·64 per cent. on ignition, whilst 5 and 6 were in garden soil containing ·138 per cent. N and losing 7·0 per cent. on ignition.

(*b*) Soil steamed August, 1905, and without further treatment 4 successive crops were raised.

		Unheated soil	Heated soil
1st crop, Turnips (Aug. 29, 1905 to Feb. 18, 1906)	Fresh weight	126·3	277·8
	Dry matter	13·0	31·25
	Relative weights of dry matter	*100*	*240*
2nd crop, Wheat (Feb. 20 to July 26)	Straw	22·5	31·87
	Relative weights	*100*	*142*
	Grain	8·0	10·73
	Relative weights	*100*	*134*
3rd crop, Buckwheat (Aug. 16 to Oct. 20)	Dry matter	6·15	5·62
	Relative weights	*100*	*91*
4th crop, Rye (Dec. 21, 1906 to July 27, 1907)	Straw	49·45	40·95
	Relative weights	*100*	*83*
	Grain	16·40	15·39
	Relative weights	*100*	*94*

(*c*) Soil steamed Jan. 1906, and cropped with *radishes*. Green weights only given.

	1st crop Feb.—April	2nd crop April—June	3rd crop June—July	4th crop July—Sept.	5th crop Sept.—Dec.	6th crop Dec.—Apr. 1907	7th crop Apr.—June
Unheated soil	22·56	18·0	22·8	29·9	7·48	20·35	30·54
Heated soil...	48·65	64·0	40·4	38·3	7·75	23·25	29·75

The soil was then heated to 95° for 2 hours and the 8th crop was sown.

Unheated soil.........	25·7
Heated soil............	47·85

(*d*) Soil steamed Aug. 1906, two successive crops raised.

	1st crop, Buckwheat (Aug. 27th to Oct.) Green wt.		*2nd crop, Rye* (Dec. 21st to July 27th, '07) Straw		Grain	
	grms.	Rel. wt.	Grams	Rel. wt.	Grams	Rel. wt.
Unheated soil......	40·56	100	68·10	100	29·39	100
Heated soil	48·05	119	95·20	140	57·11	194

Percentage composition of dry matter of the Rye crop.

	Straw N per cent.	Straw P_2O_5 per cent.	Grain N per cent.	Grain P_2O_5 per cent.
Unheated soil	·383	·278	1·10	·874
Heated soil	·454	·141	1·28	·888

In experiment (*a*) pasture soil was used containing ·182 per cent. N and losing 4·3 per cent. on ignition. Earlier investigators have sometimes stated that mustard suffers very much when grown in heated pasture soils; we have never observed any retardation at all, the plants do well right from the beginning to the end. All our soils, however, contain a liberal amount of calcium carbonate—somewhere about 10 per cent.

Effect of reinoculation after partial sterilisation by heat. Well water was used for watering. The heated soils were divided into two lots, one receiving sterilised, the other unsterilised water. The results, given in Table XI., are very interesting, and throw light on the whole

subject. They appear to indicate that so long as the new flora obtained after heating was left undisturbed, as it is by watering only with sterilised water, the usual increase in crop is obtained, but when the new flora is disturbed by the addition of unsterilised well water the crop decreases.

FIG. 1. Buckwheat growing in (1) unheated, (2) heated soil (see Table X.).

The ash of spinach grown on the heated soils was green, indicating the presence of manganese; that from the unheated soil was practically white.

Soils heated to higher temperatures. A few experiments have been made with soils heated to 120° C. The same kind of results are obtained as at the lower temperatures, but they are somewhat intensified. They are given in Table XII.

TABLE XI.

Effect of reinoculation.

		Heated soil, water sterilised	Heated soil, water unsterilised	Unheated soil, water sterilised
Spinach.	Dry matter	15·40	11·35	9·65
	Relative weights	*160*	*118*	*100*
	N per cent.	4·94	4·80	2·59
	Weight of N in crop	·761 gms.	·545 gms.	·250 gms.
Radishes.	Dry matter	4·50	2·17	1·75
	Relative weights	*257*	*124*	*100*
Clarkias.	Dry matter	6·80	4·86	2·86
	Relative weights	*238*	*170*	*100*

TABLE XII.

Effect of higher temperatures.

	Lettuce			Dianthus			Sainfoin		
	Green wt.	Dry matter	Rel. wt. of dry matter	Green wt.	Dry matter	Rel. wt. of dry matter	Green wt.	Dry matter	Rel. wt. of dry matter
Unheated soil ...	70·3	6·35	100	37·57	10·01	100	26·75	6·35	100
Soil heated to 80°	87·1	7·4	116·5	49·15	11·53	115	26·49	6·17	97·16
,, ,, 120°	108·5	9·4	148·0	72·06	17·54	175	19·45	4·52	71·2

Effect of partial sterilisation on the composition of the crop and on the amount of plant food removed from the soil.

Analysis of the crop shows that plants grown on sterilised soils usually contain an increased percentage of nitrogen and of phosphoric acid, notwithstanding their extra weight: indeed it would appear that there is often a wasteful consumption of these two substances, so great is the change in percentage composition. Even the second crop sometimes shows this difference.

The effect of volatile antiseptics is shown by buckwheat (Table VI. (*a*)), and by rye (Table VII. (*f*)): that of heat by mustard, buckwheat, rye (Table X. (*a*) and (*d*)) and wheat (Table IX. (*a*)).

The total amount of plant food withdrawn from sterilised soils is in consequence much greater than from the untreated soils: the quantities are given in Table XIII.

Discussion of results. The two main facts brought out in the course of our experiments are that after the soil has been partially sterilised there is an increase in the amount of oxygen absorbed in the soil, presumably by the micro-organisms, and also an increase in crop productiveness.

TABLE XIII.

Weights of food materials taken by plants from variously treated soils.

Amounts taken by Buckwheat (Table VI. (*a*))

	N		P_2O_5		K_2O	
	Gms.	Rel. wts.	Gms.	Rel. wts.	Gms.	Rel. wts.
Untreated soil	·499	100	·339	100	1·019	100
Soil treated with $CHCl_3$	·730	146	·615	181	1·413	139
" " CS_2	·733	147	·544	161	1·389	136
" " toluene	·629	126	·445	131	1·215	119

These results are set out in diagram form in Fig. 2.

Amounts taken by Rye (Table VII. (*f*))

	N				P_2O_5			
	In straw, gms.	In grain, gms.	Total gms.	Rel. wts.	In straw, gms.	In grain, gms.	Total gms.	Rel. wts.
Untreated soil	·075	·132	·207	100	·056	·119	·175	100
Soil treated with $CHCl_3$	·120	·166	·286	138	·081	·136	·217	124
" " CS_2	·113	·196	·309	149	·104	·167	·271	155
" " toluene	·082	·188	·270	131	·074	·159	·233	133

Successive amounts taken from heated soils (Table X.)

Amounts taken by 1st crop (Mustard)

	N		P_2O_5		K_2O	
	Gms.	Relative weights	Gms.	Relative weights	Gms.	Relative weights
Untreated soil	·367	100	·159	100	·668	100
Heated soil	1·077	293	·506	318	1·221	183

Amounts taken by 2nd crop (Buckwheat)

	N		P_2O_5		K_2O	
	Gms.	Relative weights	Gms.	Relative weights	Gms.	Relative weights
Untreated soil	·171	100	·320	100	·555	100
Heated soil	·548	320	·619	194	1·299	234

Total amounts taken by the two crops

	N		P_2O_5		K_2O	
	Gms.	Relative weights	Gms.	Relative weights	Gms.	Relative weights
Untreated soil	·538	100	·479	100	1·223	100
Heated soil	1·625	302	1·125	235	2·520	206

These results are set out in diagram form in Fig. 3.

Amounts removed by Wheat (Table IX. (*a*))

	N				P_2O_5			
	In straw, gms.	In grain, gms.	Total gms.	Rel. wts.	In straw, gms.	In grain, gms.	Total gms.	Rel. wts.
Untreated soil	·114	·227	·341	100	·089	·113	·202	100
Heated soil	·244	·708	·952	279	·224	·345	·569	282

Amounts removed by Rye (Table X. (*d*))

	N				P_2O_5			
	In straw, gms.	In grain, gms.	Total gms.	Rel. wts.	In straw, gms.	In grain, gms.	Total gms.	Rel. wts.
Untreated soil	·261	·323	·584	100	·085	·257	·343	100
Heated soil	·432	·731	1·163	199	·100	·507	·607	178

It is manifest that the bacterial flora of the soil must be profoundly changed by the process, but until the change has been more fully investigated it is useless to discuss the increased absorption of oxygen. Experiments on this question are now in hand.

We are also unable to state the ultimate cause of the increase in crop production.

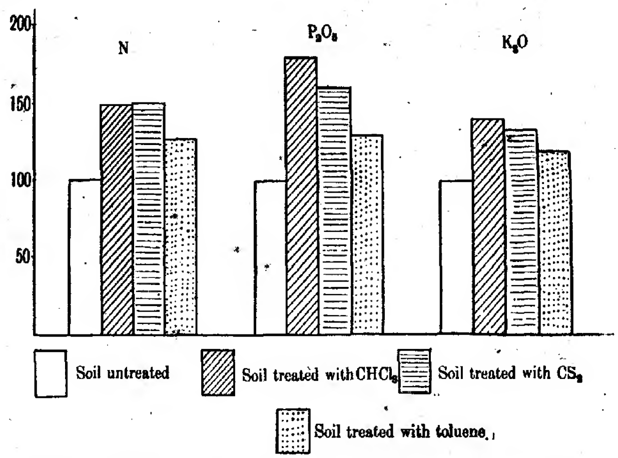

FIG. 2. Relative amounts of plant food taken by buckwheat from variously treated soils (see Tables VI. (*a*) and XIII.).

The treatment has no obvious effect on germination, the young plants appear to be all equal in size and differences only show themselves at a later date. Whatever produces the increased crop, it certainly is not an initial stimulus giving the plants such a start that the others can never overtake them; the cause persists throughout the life of the plant and even lasts on to influence a second crop. The immediate cause of the increased productiveness is no doubt the increased availability of the plant food, but how this comes about is not altogether clear.

In the case of heated soils some chemical decomposition certainly takes place. A heated soil on treatment with water yields a larger amount of soluble matter and the extract is darker in colour than before. The increase in "available" plant food is strikingly shown in Table X. (*a*) by the amounts actually removed by the plant from the

soil. From the heated soil the two crops can get three times as much nitrogen, and twice as much phosphoric acid and potash, as from the untreated, while the difference in composition of the dry matter is very considerable. The crop grown on the untreated soil is quite normal, and shows no sign of starvation or defective metabolism; its content of nitrogen and phosphoric acid seems sufficient. On the heated soils so much of these substances is presented to the plant that their percentage amount in the dry matter almost doubles; apparently we are dealing with a "luxus consumption."

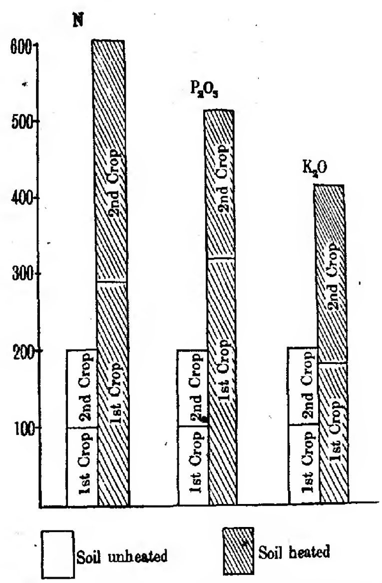

FIG. 3. Relative amounts of food taken by plants from heated and unheated soils, 1st crop, mustard, 2nd crop, buckwheat (see Tables X. and XIII.).

It is, however, impossible to explain in this way the results obtained with volatile antiseptics. No chemical reaction can take place between soils and inert bodies like toluene or carbon disulphide vapours, and yet there has been an increase in "availability." The facts are shown very clearly by the analyses in Table VI. (a). In this experiment the soils treated with chloroform and carbon disulphide are able to supply the plant with 75 per cent. more phosphoric acid, 50 per cent. more nitrogen,

and 40 per cent. more potash than the untreated soil. Indeed the increased percentage of nitrogen and phosphoric acid in the dry matter of the plants grown on partially sterilised soil suggests that they have more of these two nutrients than is really necessary.

We are compelled to have recourse to a biological hypothesis to explain these facts. Two such hypotheses have already been put forward to account for the increase in productiveness when soil is treated with carbon disulphide, and two others can be added.

A. Koch[1] supposed that carbon disulphide, being a poison, acts in small quantities as a stimulant to the plant causing it to take up more food and so make greater growth. The increase in the first crop might be thus explained, but it is exceedingly difficult to understand how a sufficient amount could remain in these well aerated and frequently watered soils to influence the subsequent crop eight months afterwards. Moreover our experiments with traces—·01 per cent. and ·001 per cent.—of non-volatile poisons, which on Koch's view ought to act as stimulants, have not shown any increase in crop.

Hiltner and Störmer[2] consider the increased productiveness is due to a change in the bacterial flora of the soil. By their method of counting they showed that the first effect of carbon disulphide treatment was to decrease by about 75 per cent. the number of organisms which can live on gelatine, this was followed by an enormous increase, particularly of certain non-liquefying forms. The change in the total number could not be determined owing to the impossibility of counting organisms which do not multiply in gelatine. They suppose that the new flora happens to be more favourable to the production of plant food than the old; as an instance they mention the total destruction of the denitrifying organisms[3].

A third possibility is that partial sterilisation removes a number of organisms which, without benefiting the plant, compete with it for whatever food happens to be present in the soil; when they are killed off a larger amount of food is left available for the plant. This view explains a good deal, but it is difficult to reconcile with the increased absorption of oxygen by the partially sterilised soils. If the number of

[1] *Arbeiten der deutschen Landwirtschafts-Gesellschaft*, Heft 40, 1899.

[2] *Arbeiten aus der Biolog. Abteilung für Land- und Forstwirtschaft am Kaiserlichen Gesundheitsamte*, 1903, Bd. 3, Heft 5. For figures confirming their results see Heinze, *Centralblatt für Bakt. und Parasitenkunde*, 1907, II. abt. 18, 56.

[3] Gerlach, *Bied. Cent.* 1898, 27, 717, had suggested that the increased productiveness was due to the destruction of these organisms.

organisms decreases to the extent indicated by the availability of the plant food there should be a decrease in the amount of oxygen absorbed; the contrary is, however, the case. There are, however, a number of indications that this diminished competition is an important factor.

The fourth hypothesis is an extension of the one formulated by Hiltner and Störmer, and has the advantage of connecting the increased productiveness with the increased oxygen absorption. If we suppose the latter indicates a greater activity of the new bacterial flora it follows that the rate of decomposition in the soil is hastened. The reactions accelerated include the conversion of organised plant and animal matter into humus and mineral substances, the formation of ammonia and the fixation of nitrogen, while the additional carbon dioxide evolved assists the solution of mineral matter. All these reactions contribute to the making of plant food: any increase in the rate at which they take place will increase the productiveness of the soil.

An interesting question that arises is the form in which the nitrogen is taken up. It is generally supposed that a temperature of 90°, or treatment of the antiseptics we used, would be fatal to nitrifying organisms, yet out plants evidently had no difficulty in taking up nitrogen. Beyond watering with sterilised water and keeping the house as free from dust as possible we took no special precautions to prevent reinoculation; it would, however, be difficult to believe that the uniform increases in crop we have had, especially with heated soils, can be due to chance inoculation with nitrifying organisms. We must suppose either that the nitrifying organisms are less easily killed than is generally believed, or that the plants took up some nitrogen compound other than nitrates. Further experiments on this question are required.

Conclusions.

1. Partial sterilisation of soil either by heating to 100° or by treatment with volatile antiseptics which are subsequently removed leads to a marked increase in the amount of oxygen absorbed by the micro-organisms of the soil.

2. The yield of non-leguminous crops is distinctly larger on partially sterilised than on unsterilised soils. Leguminous crops, however, show no increase.

3. Analysis shows that partial sterilisation causes an increase in the amount of nitrogen, phosphoric acid and potash taken up by the crop, and in the percentage of nitrogen and phosphoric acid in the dry matter. In other words it increases the "availability" of these plant foods.

4. The increased availability of the plant food appears to be connected with the modification of the bacterial flora brought about by partial sterilisation. When the soil is heated, however, chemical decomposition also takes place.

NOTES ON THE HOP MILDEW (*SPHAEROTHECA HUMULI* (DC.) BURR.[1]).

By E. S. SALMON, F.L.S.,

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I. *On the dehiscence of the perithecium.*

It is only quite recently that the perithecium, ascocarp or sporocarp, as it has been variously called, of the *Erysiphaceae* has been shown to possess a regular dehiscence accompanied by the ejection of the ascospores. We find the fact first recorded, I believe, by Worthington G. Smith[2], in 1884. In 1903 I independently observed the phenomenon in the same species, viz. *Erysiphe Graminis* DC., which Smith had studied. Smith's observations seem to have been entirely overlooked until attention was called to them in my paper[3] in 1903, and up to this date the perithecium of the *Erysiphaceae* is described in nearly all text-books as a *cleistothecium* or *cleistocarp*, since it was supposed to remain closed until it decayed and ruptured to permit of the escape of the ascospores.

The following account of the dehiscence of the perithecium of *E. Graminis* is taken from my paper mentioned above. "It was found that the perithecium opened spontaneously; the ascospores were forcibly ejected into the air, and were found germinating in drops of water condensed on the cover of the Petri dish, at a distance of 2 cm. from the perithecium....The dry perithecium is usually concavo-convex, but on absorbing moisture it becomes biconvex. It opens by a horizontal slit, somewhere about the equatorial plane, at one side. The slit gradually extends further and further round, while the upper half of the perithecium, like a lid, becomes lifted up. This circumscissile dehiscence sometimes results in the upper convex half of the perithecium falling away, and the lower exposed basal half remains fixed in the pannose mycelium. The actual dehiscence is in all probability brought

[1] From the Botanical Laboratory, South-Eastern Agricultural College, Wye, Kent.

[2] *Diseases of Field and Garden Crops*, p. 133, 1884.

[3] *Journal of Botany*, p. 161, 1903.

about by the swelling of the mucilaginous cells of the inner wall of the perithecium."

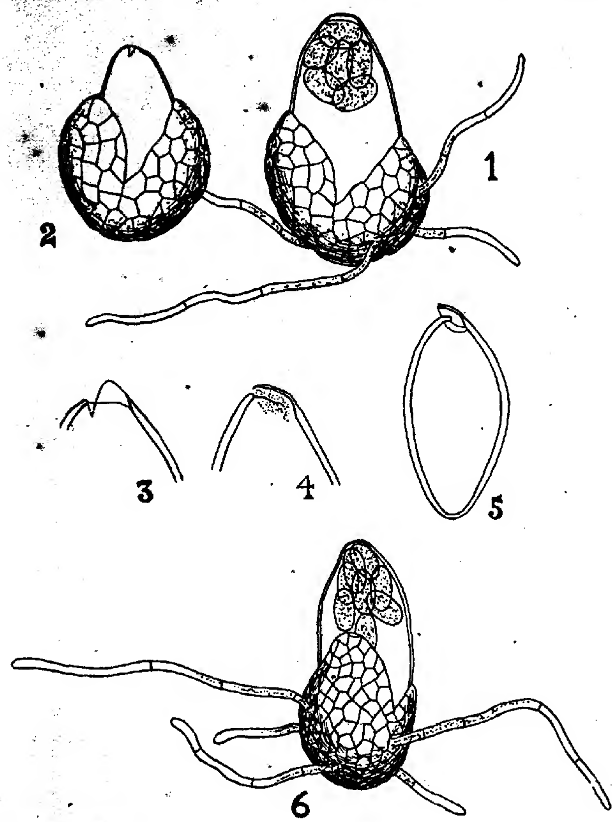
I observed during last spring the dehiscence of the perithecium of the Hop-Mildew (*Sphaerotheca Humuli* (DC.) Burr.). The process is somewhat different from what takes place in *E. Graminis*, as described above. The following experiments were made.

Experiment 1. On April 27 some dried moulded "hops" were soaked in distilled water for a few minutes, and then at once (at 11 o'clock) placed on damp blotting-paper in several Petri dishes. By 7 o'clock, that is, after 8 hours, hundreds of ascospores had been ejected from the perithecia, and were visible in the drops of water which had condensed on the lid. In other cases the lid of the Petri dish had been covered on the inside with a film of agar-agar or of gelatine, and to these also many hundreds of ejected ascospores had adhered. In some cases the ascospores had been ejected to a distance of 1·5 cm. The hops used, which were covered with perithecia, had been taken in January from a stack of hopbine and moulded hops standing in a farmyard, and had been kept dry subsequently in the laboratory.

Experiment 2. On May 1 some dried moulded "hops," obtained and treated as above, were soaked for a few minutes in distilled water, and then at once (at 12 o'clock) placed in the open on the surface of some lately dug ground in a garden. The lid of a Petri dish lined on the inside with a film of gelatine was placed just over the "hops." By 3 o'clock, that is, in 3 hours, hundreds of ascospores had been thrown up from the perithecia, and could be seen adhering to the gelatine. The ground on which the moulded "hops" were laid was moist, though not very wet. The weather was showery, sunny at times, and with occasional hailstorms; the wind was cold. A fresh lid was placed over the "hops" at 3 o'clock, and by 6 o'clock numerous further ejections had taken place, and hundreds of ascospores were visible on the gelatine film.

Experiment 3. On May 2 some dried moulded "hops" (taken from a stack in April, and kept dry subsequently) were soaked in water for a few minutes, and then a number of perithecia were lifted off with a needle and placed on wet blotting-paper at the bottom of a Petri dish. A cover slip with a thin film of gelatine was supported on a stand at a distance of 1 cm. from the perithecia, and kept continuously under observation. In 35 minutes the perithecia began bursting, and a number of ascospores were shot up on to the gelatine film. At the end of 1 hour some hundreds of ascospores were visible on the gelatine.

The details of the dehiscence of the perithecium and ejection of the ascospores were then more closely followed. Perithecia were put into a damp chamber or hanging drop of water. In some cases the perithecia which were used were taken straight from a stack of hopbine



and moulded "hops" in a farmyard; in other cases from moulded "hops" and hop leaves which had been kept dry for some months in the laboratory. The results obtained were the same in both cases. After being kept for a short time (in some cases after 1 hour) in a drop of water, the perithecium begins to split by a more or less vertical

slit from the apex (see Figs. 1 and 6). At once the apex of the ascus appears at the slit, and the ascus then rapidly swells by taking up water until it protrudes sufficiently to show the enclosed ascospores (Fig. 6). The ascus continues to swell, until it reaches dimensions often considerably exceeding those of the perithecium in which it was originally contained (see Fig. 1). At this stage the walls of the ascus are in a state of considerable tension; the ascospores are usually collected close under the pore at the apex of the ascus (Fig. 1). In a few minutes the ascus bursts by a small slit at its apex (Figs. 3, 4, 5), and the ascospores are forcibly expelled altogether. The now empty ascus at once contracts and shrinks back into the perithecium, the walls of which come nearer together at the opening. Figs. 1 and 2 show the same perithecium before and after the expulsion of the ascospores; in Fig. 2 the shrunken ascus is seen partly withdrawn into the perithecium. In some few instances, where the perithecium was placed in a hanging drop of water, I have observed the ascus to slip entirely out of the perithecium, soon after the latter has split, before the expulsion of the ascospores. In such cases, which are quite rare, the ascus soon bursts at the apex, as shown at Fig. 5, and discharges the spores,—showing that this process can take place quite independently of the perithecium.

In no instance have I observed any forcible ejection of the ascus from the perithecium, and it seems certain that this does not take place; as a rule the ascus does not even leave the perithecium, but behaves as shown in Figs. 6, 1, and 2. Smith (*l.c.*) has stated that in *E. Graminis* the asci as well as the spores are ejected from the perithecium, but in my observations on that species I was not able to confirm his statement.

It may be mentioned here that I have not succeeded in inducing perithecia of *S. Humuli* collected in the autumn to burst and eject the spores before they have passed through a resting period of some months. The perithecia of *E. Graminis*, as I have shown elsewhere, do not require any resting period.

II. *Inoculation experiments with ascospores.*

Experiment 1. On April 21 some dried moulded "hops" were placed on damp blotting-paper in a Petri dish. By April 23 the perithecia had burst, and thrown up many hundreds of ascospores, which could be seen floating in the little drops of water condensed on the lid of the dish. Many of these spores had already commenced

to germinate. A number of these ascospores were now transferred to the upper surface of a marked leaf of a young (seedling) hop. Seven days later a small patch of *Oidium*, already powdery with conidia, was visible on the marked leaf, at the spot where the ascospores had been sown.

Experiment 2. On April 29 some hundreds of perithecia which had just arrived at the stage of bursting and ejecting spores, were sown on the upper surface of a marked leaf of a seedling hop, and also of a young plant of *Potentilla reptans*. By May 6 a fairly large, powdery patch of *Oidium* had appeared on the hop leaf at the place where the perithecia had been sown. By May 12 this had developed into a large, very conspicuous, white, densely powdery patch. No trace of infection resulted on the *P. reptans*.

Experiment 3. On May 1 a young leaf of a seedling hop and a young leaf of a plant of *P. reptans*—in both cases attached to the plant—were laid upon some moulded "hops" which at the time were ejecting ascospores from the perithecia. The leaves remained in this position for 24 hours, when the two plants were placed under a bell-jar. At the end of 9 days, a vigorous, powdery patch of *Oidium* appeared on the leaf of the hop. No trace of infection resulted on the leaf of *P. reptans*.

Experiment 4. Another experiment, exactly similar, started on May 2, gave the same results, viz. the infection of the hop, but not of *P. reptans*.

Experiment 5. On May 11 drops of water containing many hundreds of recently ejected ascospores were placed on a leaf of a young hop, and on a leaf of *Spiraea Ulmaria*, in each case within a marked area on the leaf. On May 21 some delicate radiating mycelial hyphae and a few scattered conidiophores were visible at the marked place on the hop leaf. On May 26 a conspicuous powdery patch of *Oidium* had developed on the hop leaf at the marked place only. No trace of infection resulted on the *S. Ulmaria*.

Experiment 6. On May 12 conidia were taken from the *Oidium* patch produced on the hop leaf in the above experiment, and sown on a marked leaf of a hop and on a marked leaf of *S. Ulmaria*. By May 26 a powdery patch of *Oidium* had been produced at the marked place only on the hop leaf; no trace of infection occurred on the *S. Ulmaria*.

We may conclude from the above inoculation experiments that the mildew on the Hop is, at least to a certain extent, a distinct "biologic

form," since it is unable to infect *P. reptans* and *S. Ulmaria*, both host-plants of the morphological species *S. Humuli*. I have previously shown[1] that the conidia of the form of *S. Humuli* on *P. reptans* are unable to infect *Alchemilla vulgaris*, *A. arvensis*, *Fragaria* sp., *Spiraea Ulmaria*, *Agrimonia Eupatoria*, and *Poterium officinale*,—all of which are host-plants of the species. The same specialisation of parasitism has been proved (*l.c.*) to exist in the case of the variety *fuliginea* of *S. Humuli*.

All the evidence, then, shows that the morphological species *S. Humuli* consists of a number of specialised "biologic forms," each of which is incapable of infecting any of the host-plants of the others. The point is of some economic importance. It has been the habit of agricultural writers who have treated of "hop mildew" or "mould" in connection with the cultivation of hops, to call attention to the fact that this mildew lives on a number of wild plants, such as "Meadow Sweet" (*Spiraea*) and Avens (*Geum*); and then, having assumed that the mildew could pass from these plants on to cultivated hops, these writers have advised the hop-grower to spray, or to get rid of, these "mouldy" wild plants[2].

From our present knowledge of the specialisation of parasitism of *S. Humuli*,—as well as of the high degree of specialisation which has been proved to exist in the *Erysiphaceae* generally[3],—the hop-grower should not be recommended to take any special steps to deal with mildewed weeds in or near the hop-garden. The whole of the evidence to hand strongly supports the view that hop "mould" is due to one special "biologic form" confined to *Humulus Lupulus* and *H. japonicus*, and that consequently hop-growers have nothing to fear from other forms of *S. Humuli* growing on wild plants. It must be pointed out, however, that until inoculation experiments with all the forms of the fungus on the thirty or more host-plants[4] on which it occurs in this country have been carried out, the bionomics of the morphological species *S. Humuli* must remain only partly known.

[1] *The New Phytologist*, III. p. 111, 1904.

[2] See *e.g.* Percival, *Agric. Botany*, p. 732, 1902; *Journ. Bath and West of England Soc.* XV. p. 78; Myrick, *The Hop*, p. 152 (1899).

[3] See Salmon, E. S., "Recent Researches on the Specialisation of Parasitism in the *Erysiphaceae*," *The New Phytologist*, III. p. 55, 1904; *l.c.* p. 109, where a bibliography of the subject is given.

[4] See Salmon, E. S., Monograph of the Erysiphaceae, 1900, and "Supplementary Notes," *Bull. Torr. Bot. Club*, 1902.